PM012 – 11 January 2024
Update on PINNs

Application to Urban Wind Field Dispersion Studies

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Script Version v5

1) PINN is now completely customizable – customizable input and output parameters, batch normalization, dropout rate, neuron number, number of hidden layers – all options in the config file (PM007)
2) Saving of all the losses (not just the total loss) (PM007)
3) Plotting of loss vs epochs now automatic (PM007)
4) Boundary conditions – relaxed no slip condition included (PM007)
5) New angles included (PM007)
6) Smaller batch sizes (I disagree) – customizable from config file (PM007)
7) Testing and Predicting Loss during training phase (PM008)
8) Inlet Boundary Conditions added (PM008)
9) Inlet Boundary for the Z-direction made to follow a log equation (PM009)
10) Debugged for no slip loss BC (PM009)
11) Activation function updated to an exponential linear unit instead of ReLu {arXiV: 1511.07289} (PM0010)
12) Entire script revamped for optimisation (PM011)
13) Adaptive Weighting Scheme implemented (PM011)
14) Moving averages for stopping condition implemented (PM011)
15) Amount of data to be considered for data loss is configurable (PM011)
16) Plotting divergence implemented (PM011)
17) When running in batch mode, each batch now contains a fair representation of all angles in the training phase (PM011)
18) Script has been modified for TPU use for data loss only (PyTorch → Tensorflow) (PM011)
19) Divergence computations now compares numerical differentiation on the unstructured grid vs PyTorch's autograd (PM012)

Scripts v4 – Preliminary Results

Some Parameters

Infinite epochs - instead the criteria for stopping is loss_{n} - loss_{n-1} < ε for 10 consecutive epochs where n is the epoch number and ε = 1E-5 (user defined)

128 Neurons for the PINN unless otherwise specified

We have the data for 13 angles, [0, 15, 30, 45, 60, 75, 90, 105, 120, 135 150, 165, 180] in degrees

We concatenate the data for angles = [0, 15, 30, 45, 60, 75, 90, 105, 120, 150, 165, 180] and then take 99% of the dataset with random seed = 42 for training and 1% for testing

By using 99% of the whole dataset we hope to make the NN learn about wind angle such that the parameters become functions of the wind angle

Then using the trained neural network we predict the data for angle = 135

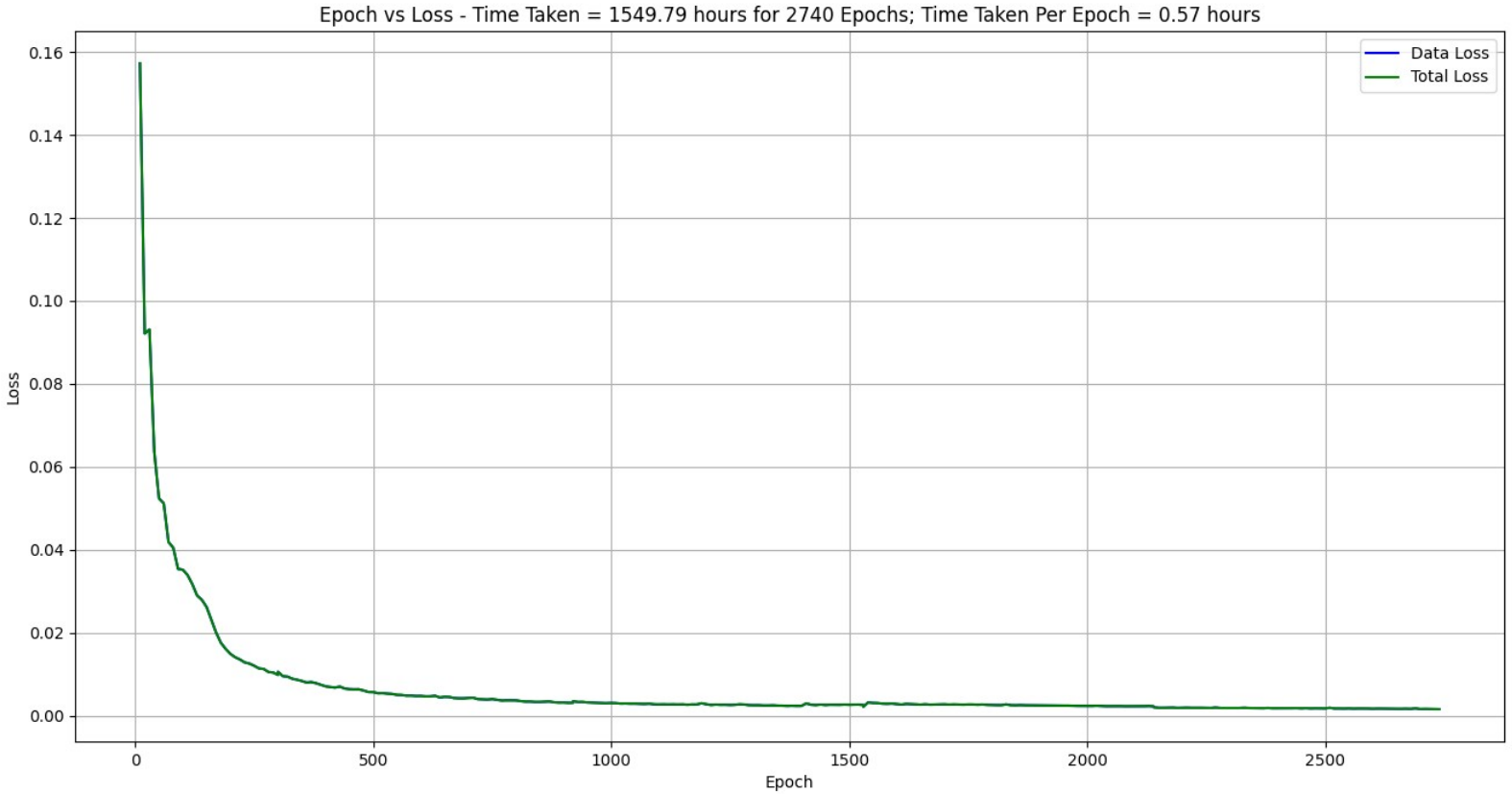
For this run, we will only have input parameters to be [X, Y, Z, cos(\theta), sin(\theta)] and the output parameters will be [U, V, W]

Progress so far - Data Loss Only
Standard Normal Scalar – ELU Activation
(Adam Optimizer)

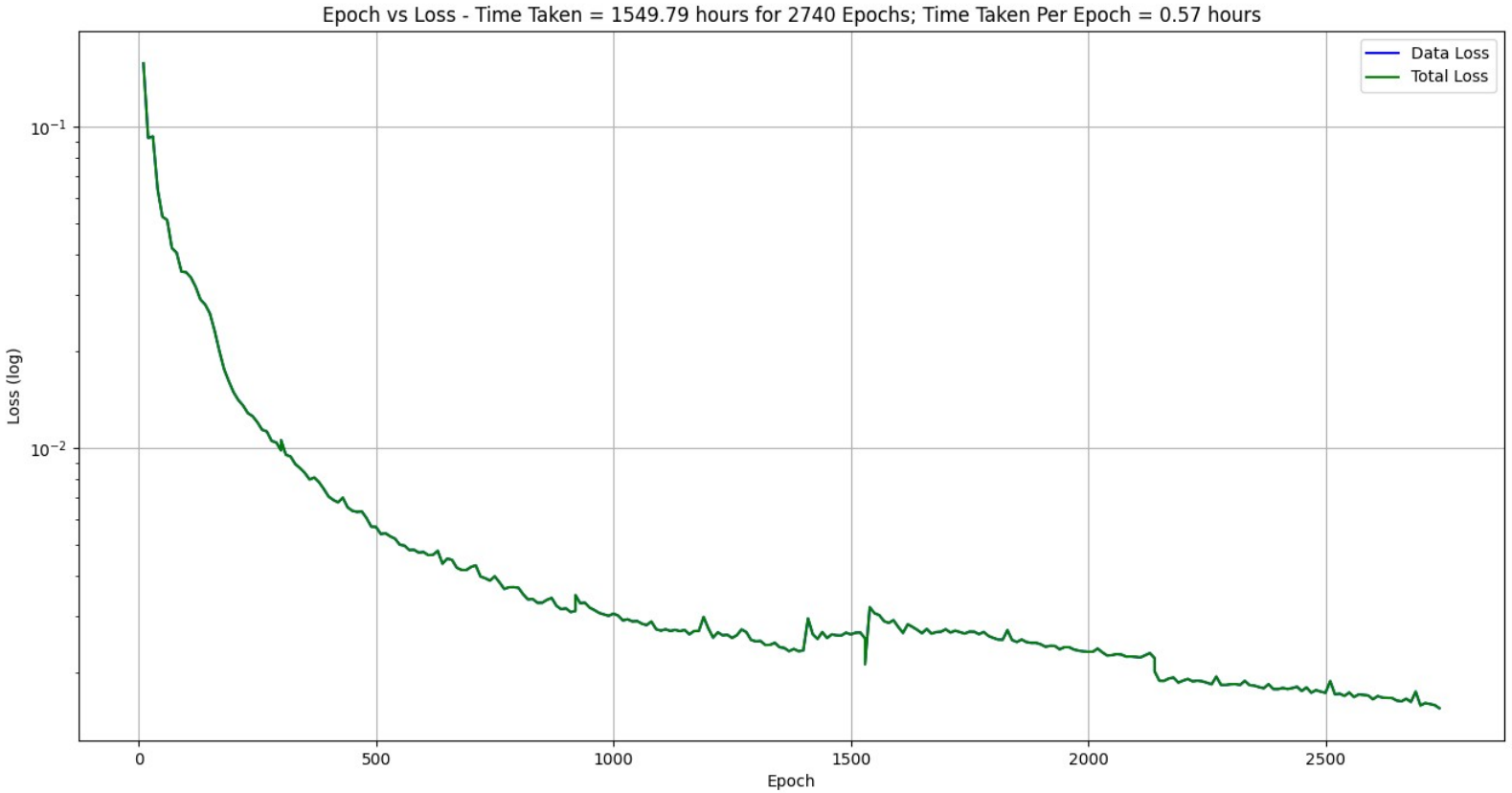
Threshold = SMA 1E-5 (2740 Epochs, not completed), GPU Laptop

Scripts v5 – TESTING

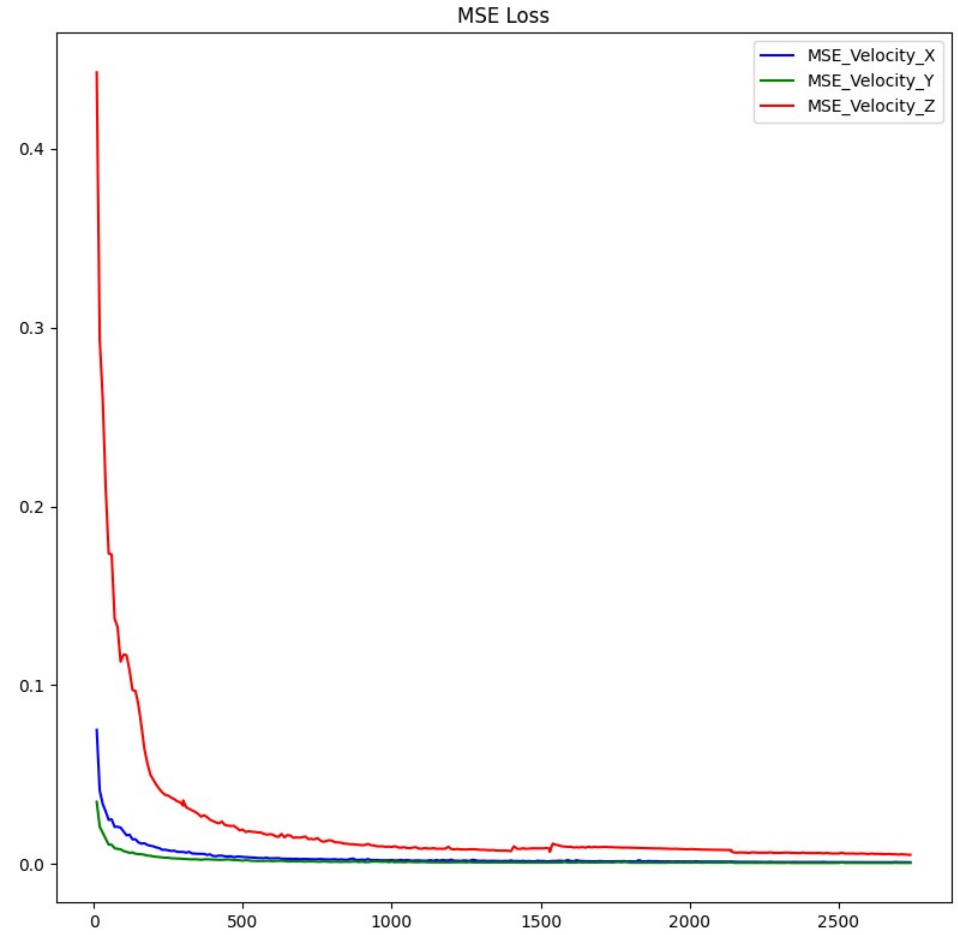
Progress so far - Data Loss Only, Standard Normal Scalar, ELU Activation, Adam Optimizer
Threshold = SMA 1E-5 (2740 Epochs, not completed), GPU Laptop
Logging Plots (Training)

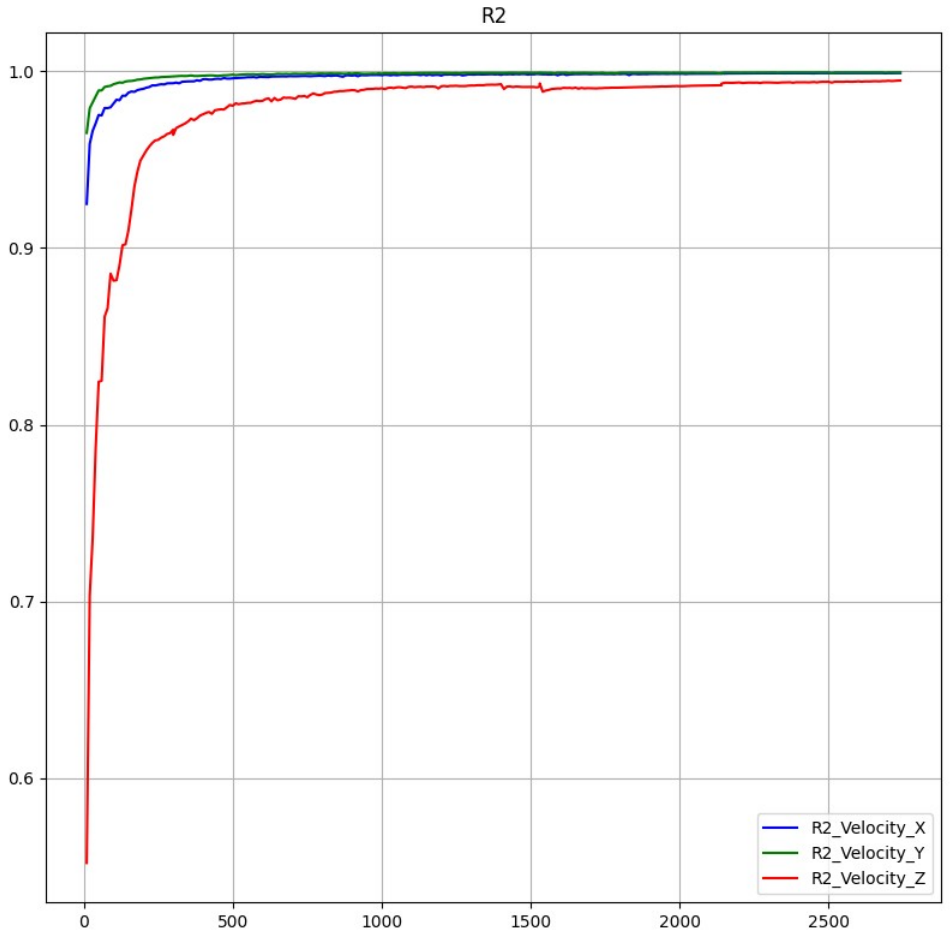


Progress so far - Data Loss Only, Standard Normal Scalar, ELU Activation, Adam Optimizer
Threshold = SMA 1E-5 (2740 Epochs, not completed), GPU Laptop
Logging Plots (Training)

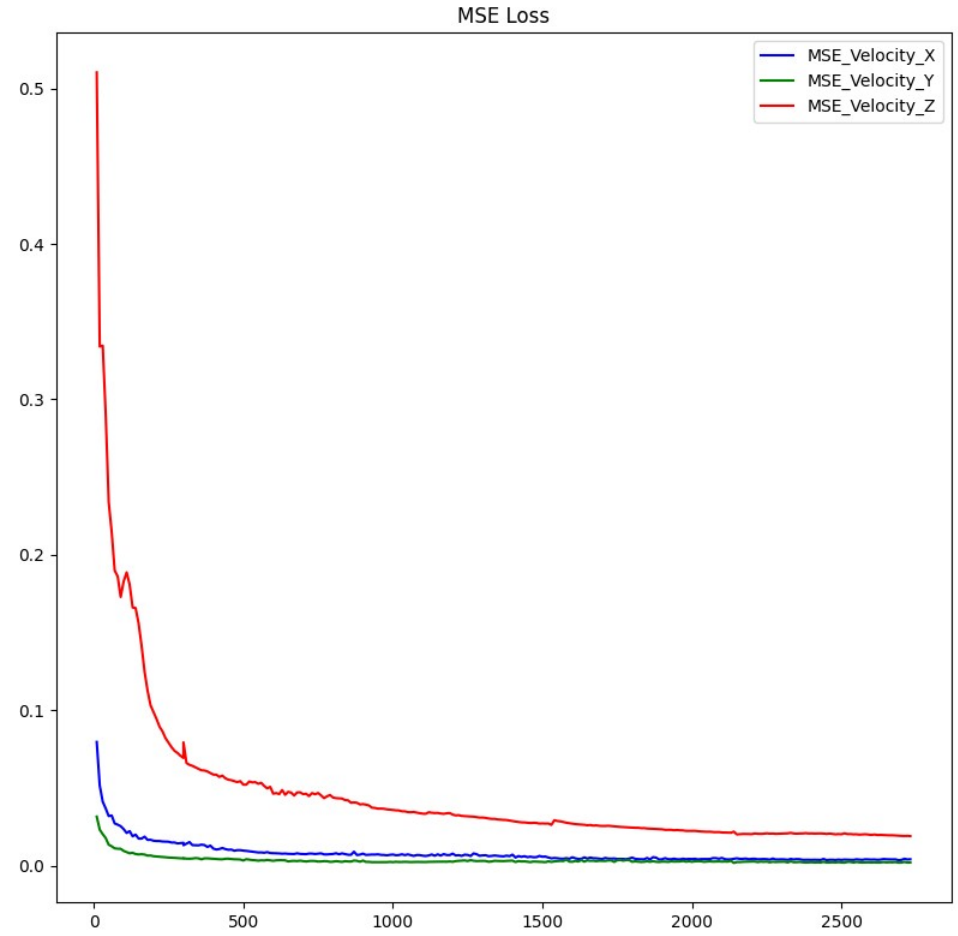


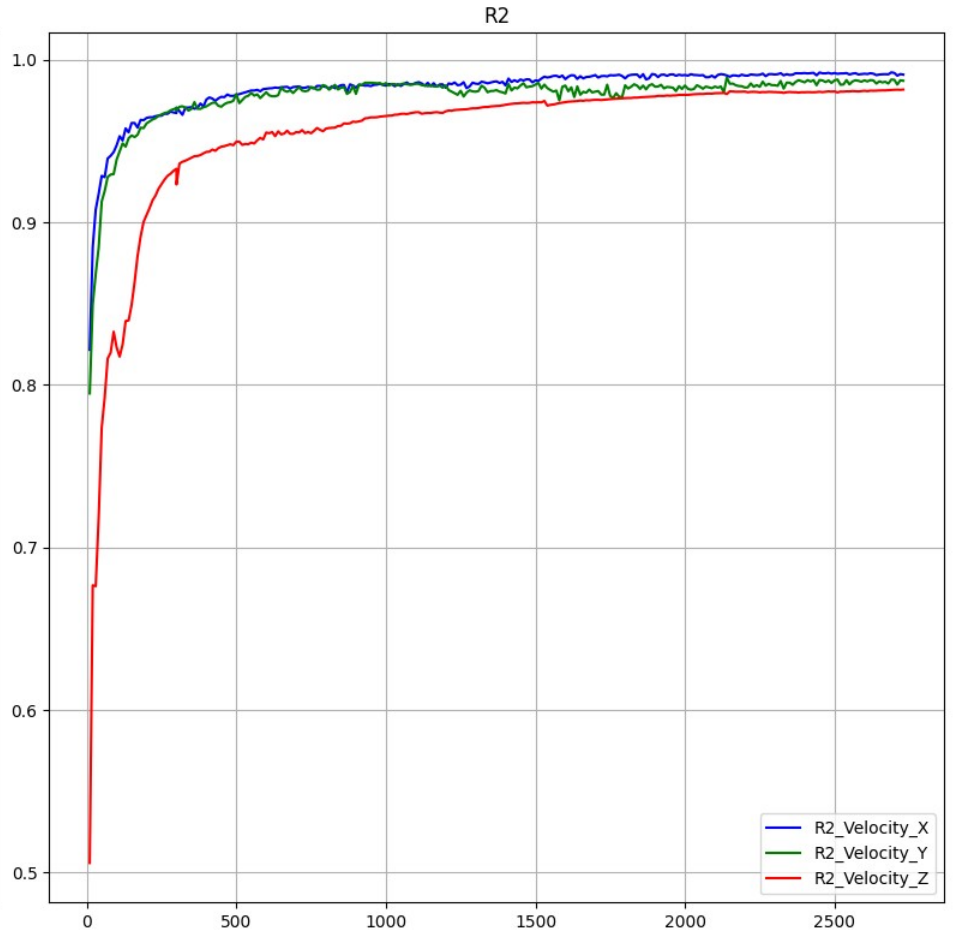
Progress so far - Data Loss Only, Standard Normal Scalar, ELU Activation, Adam Optimizer
Threshold = SMA 1E-5 (2740 Epochs, not completed), GPU Laptop
Logging Plots (Testing)

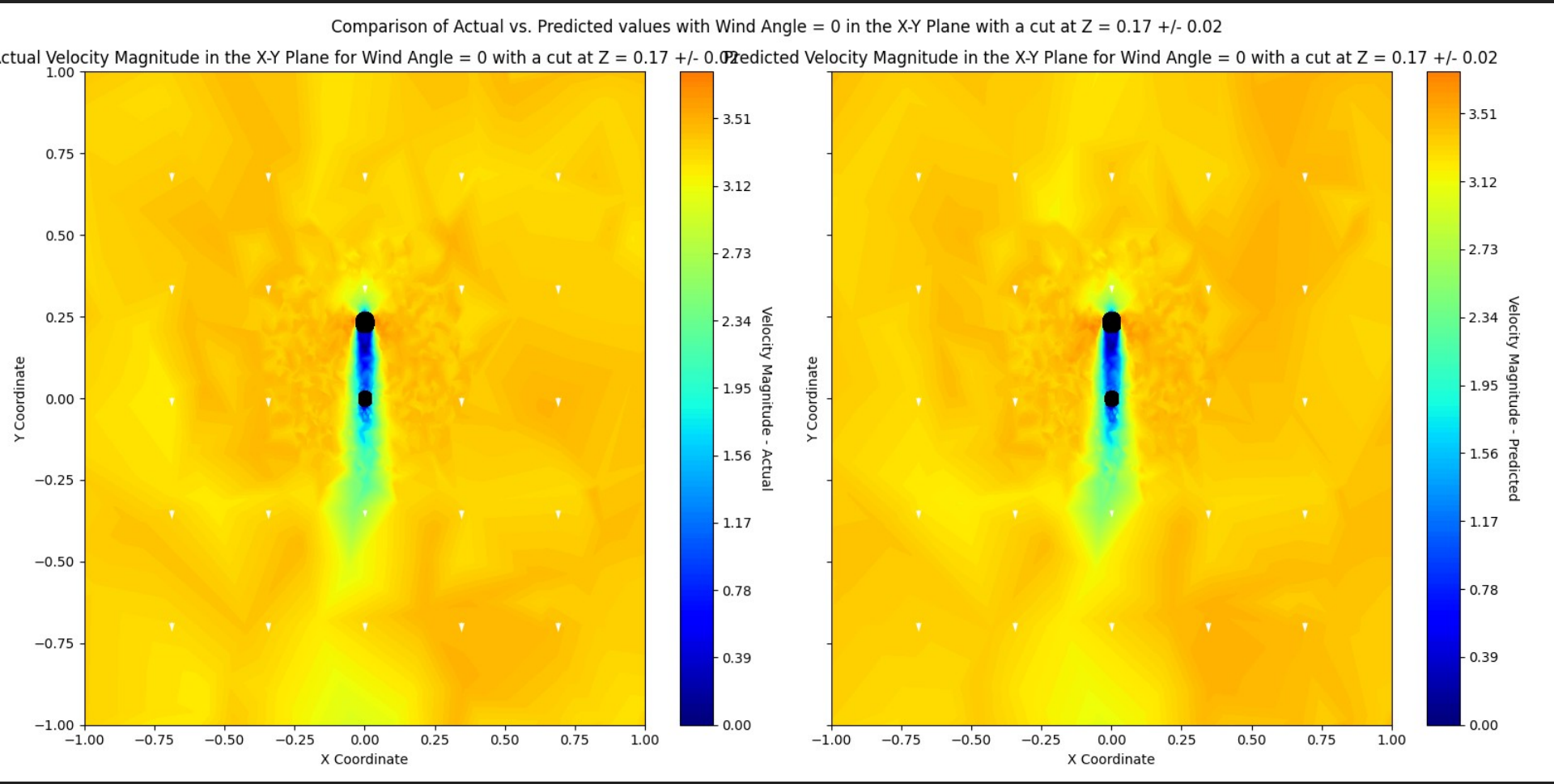


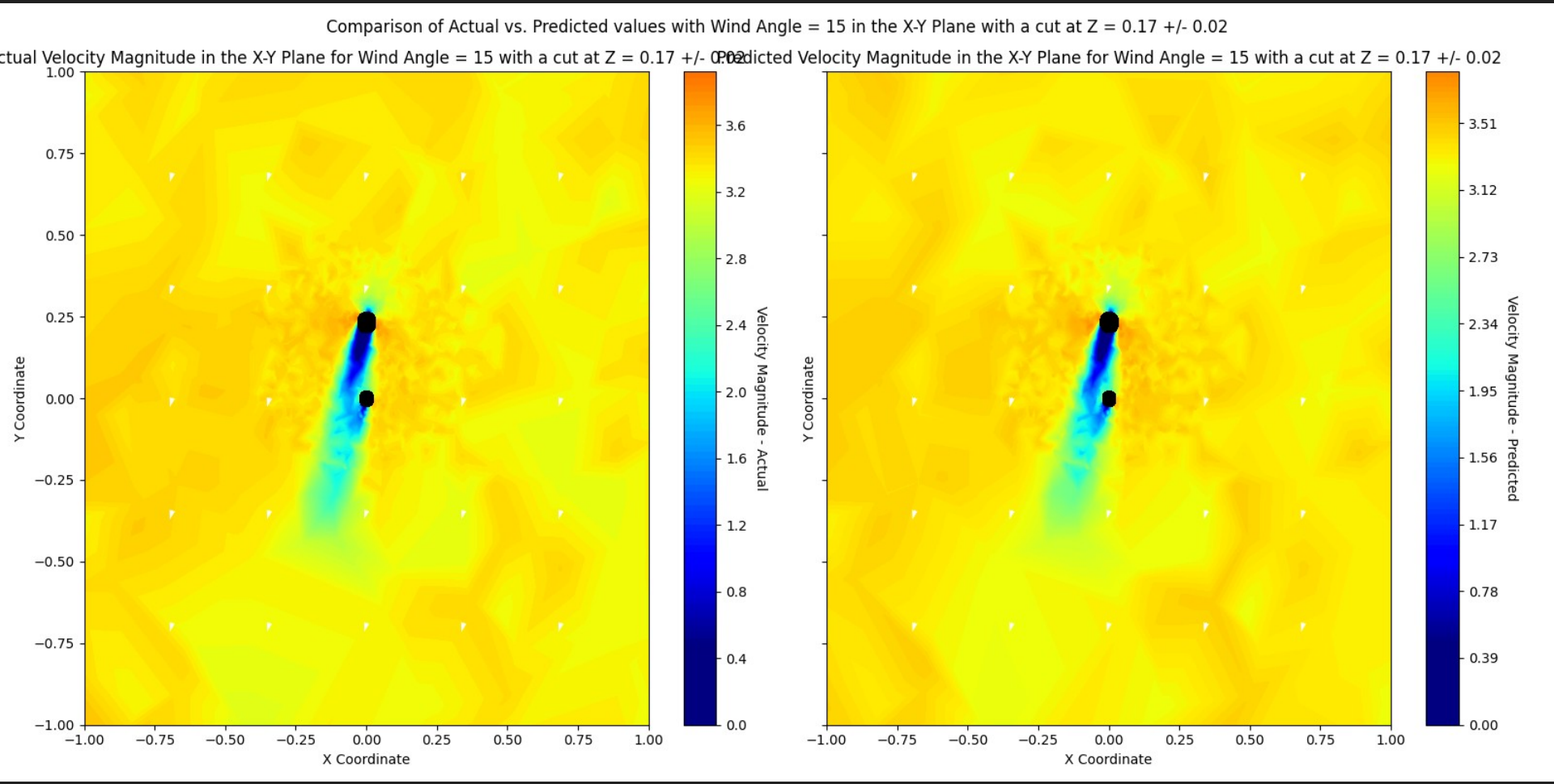


Progress so far - Data Loss Only, Standard Normal Scalar, ELU Activation, Adam Optimizer
Threshold = SMA 1E-5 (2740 Epochs, not completed), GPU Laptop
Logging Plots (Predicting 135)

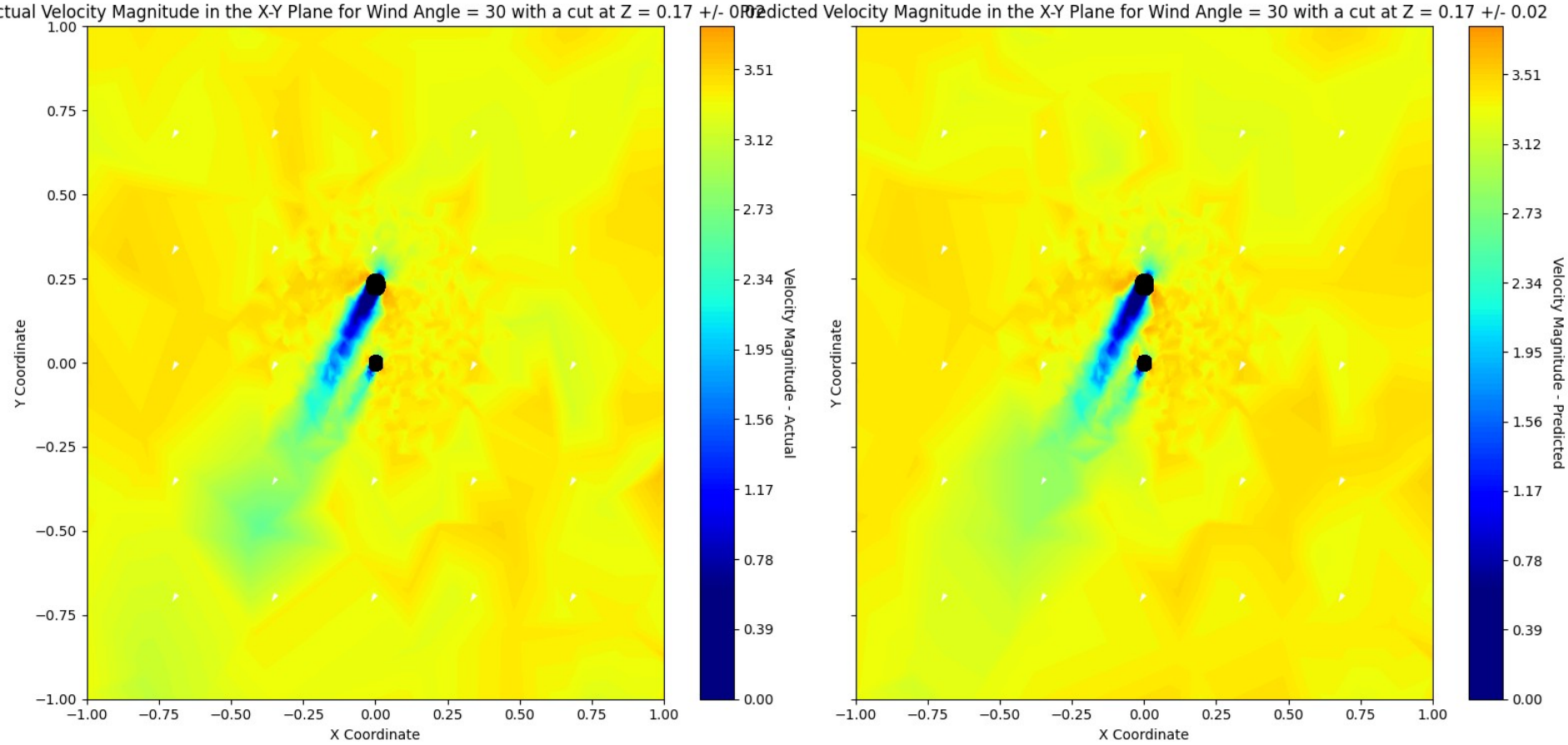




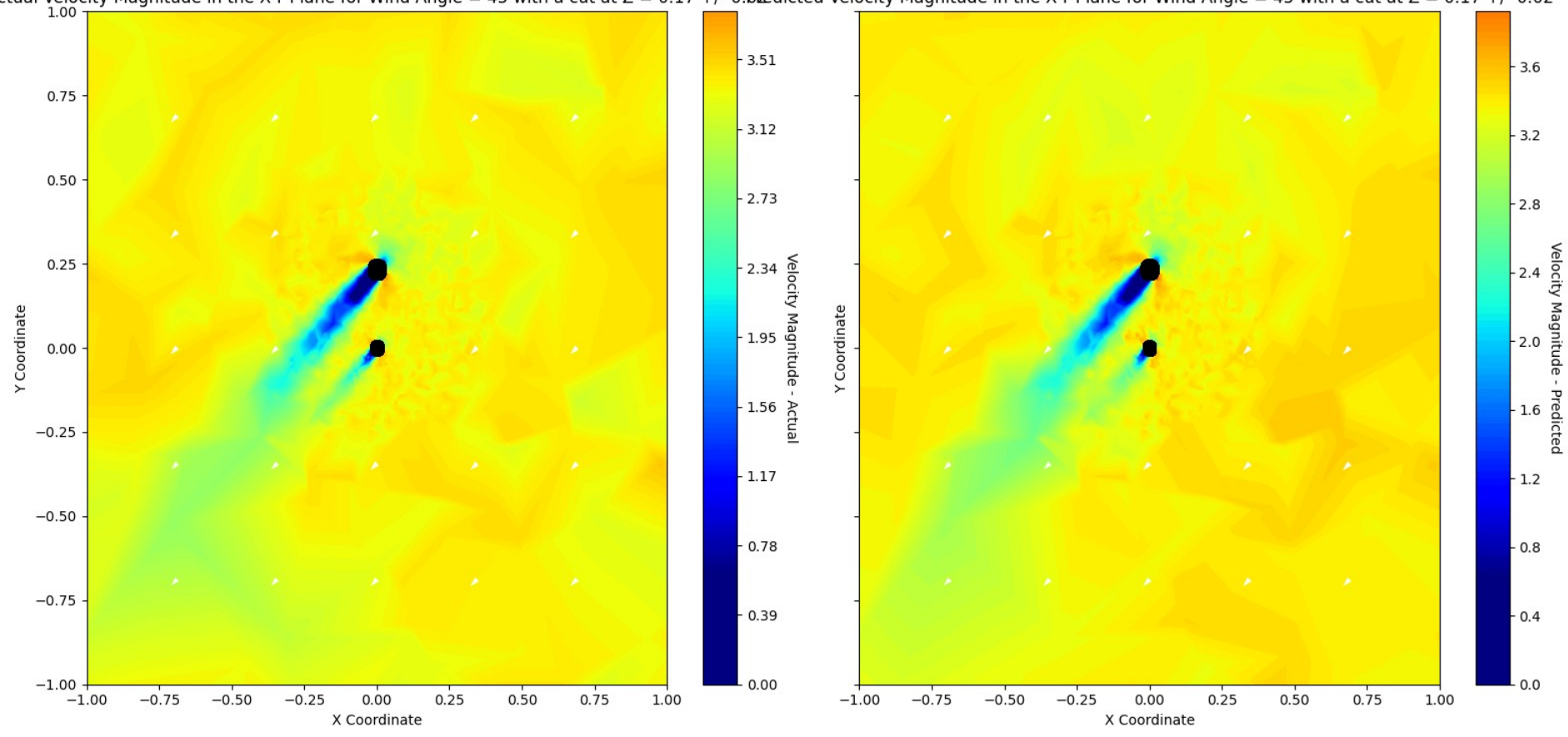

Comparison of Actual vs. Predicted values with Wind Angle = 0 in the X-Y Plane with a cut at Z = 0.17 +/- 0.02
ctual Velocity Magnitude in the X-Y Plane for Wind Angle = 0 with a cut at Z = 0.17 +/- 0.02
Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 0 with a cut at Z = 0.17 +/- 0.02
Y Coordinate
X Coordinate
Velocity Magnitude - Actual
Velocity Magnitude - Predicted
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
3.51
3.12
2.73
2.34
1.95
1.56
1.17
0.78
0.39
0.00

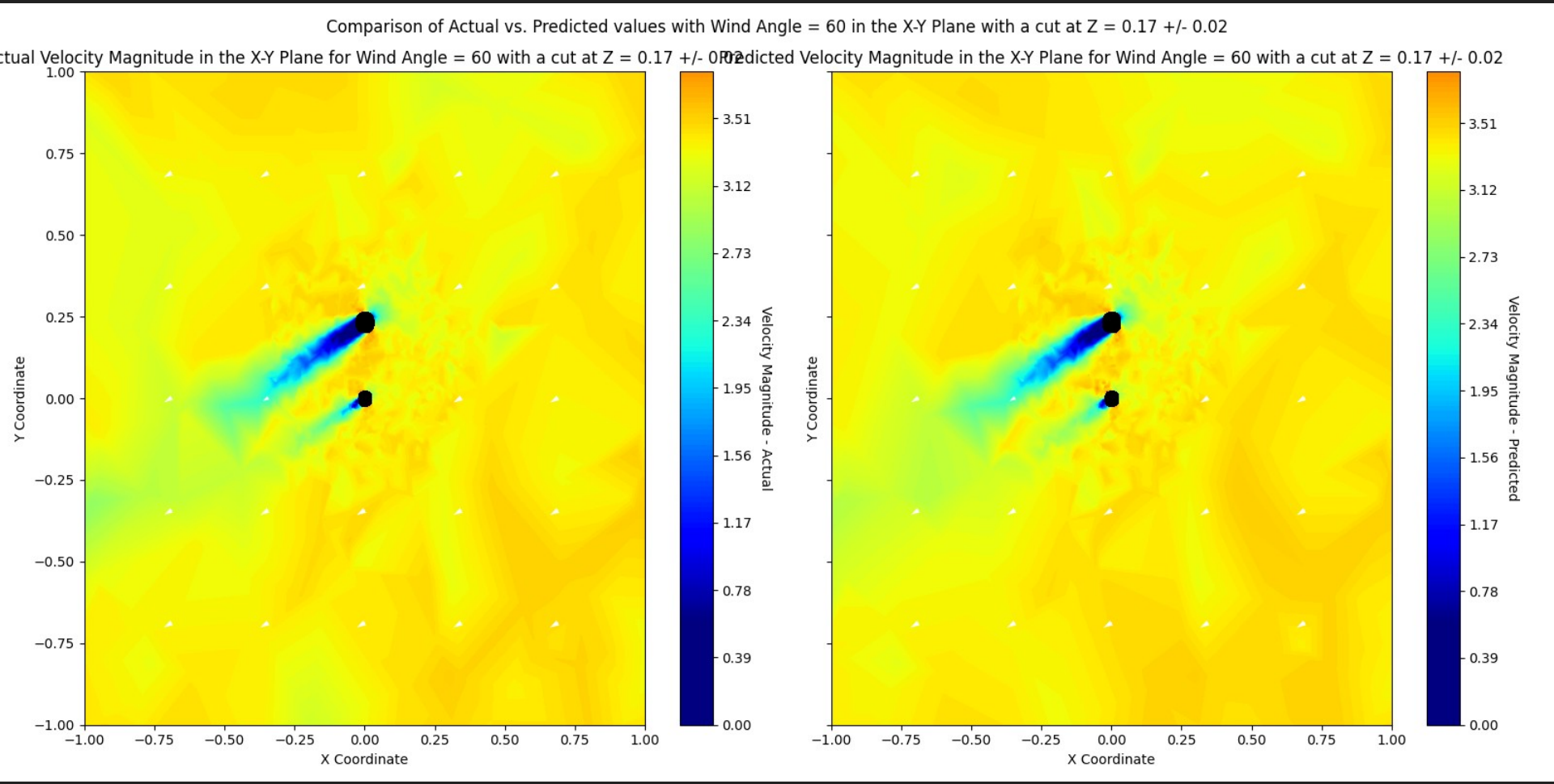

Comparison of Actual vs. Predicted values with Wind Angle = 15 in the X-Y Plane with a cut at Z = 0.17 +/- 0.02
ctual Velocity Magnitude in the X-Y Plane for Wind Angle = 15 with a cut at Z = 0.17 +/- 0.02
dicted Velocity Magnitude in the X-Y Plane for Wind Angle = 15 with a cut at Z = 0.17 +/- 0.02
Y Coordinate
X Coordinate
Velocity Magnitude - Actual
Velocity Magnitude - Predicted
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
3.6
3.2
2.8
2.4
2.0
1.6
1.2
0.8
0.4
0.0
3.51
3.12
2.73
2.34
1.95
1.56
1.17
0.78
0.39
0.00

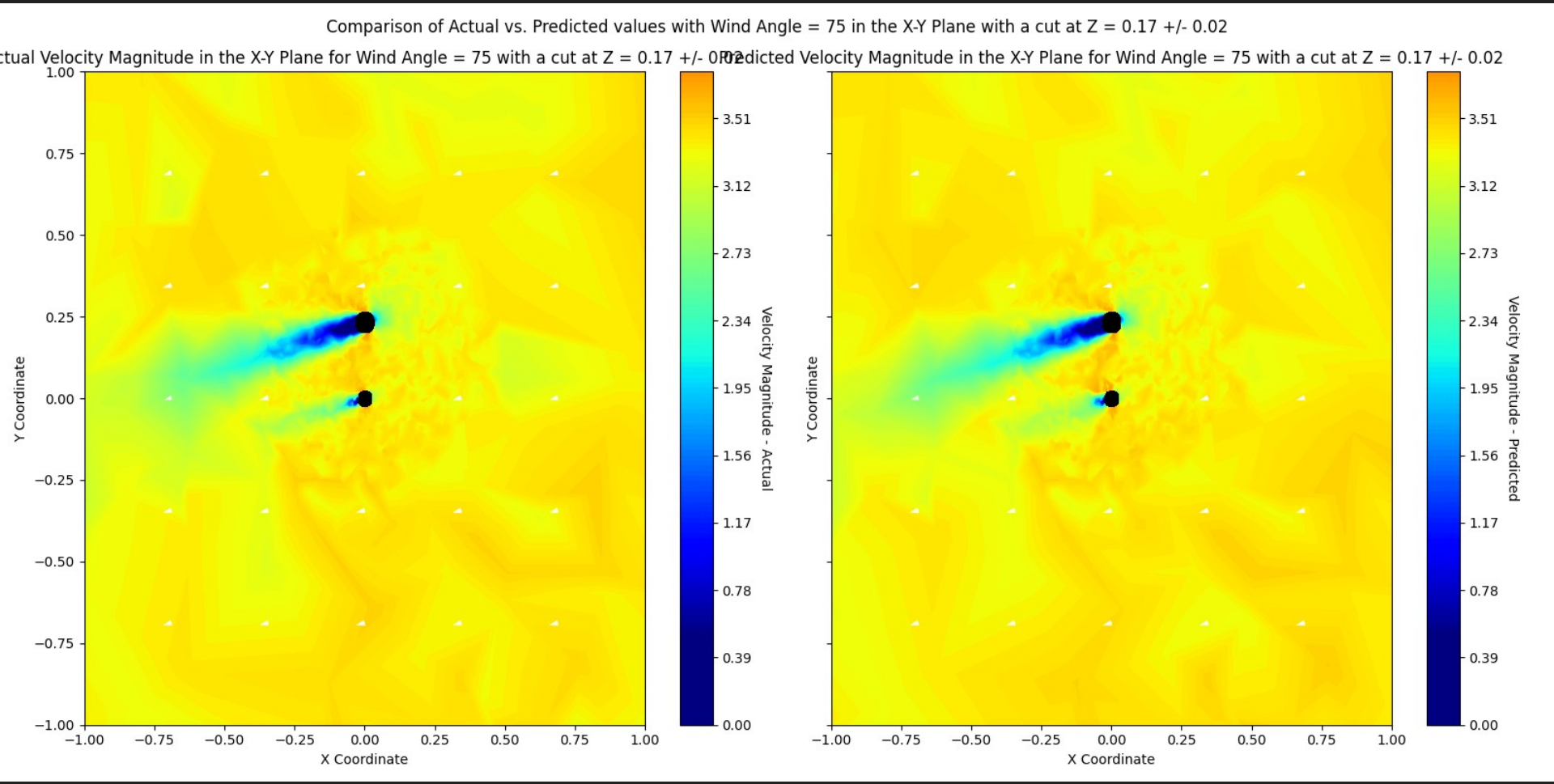
Comparison of Actual vs. Predicted values with Wind Angle = 30 in the X-Y Plane with a cut at Z = 0.17 +/- 0.02

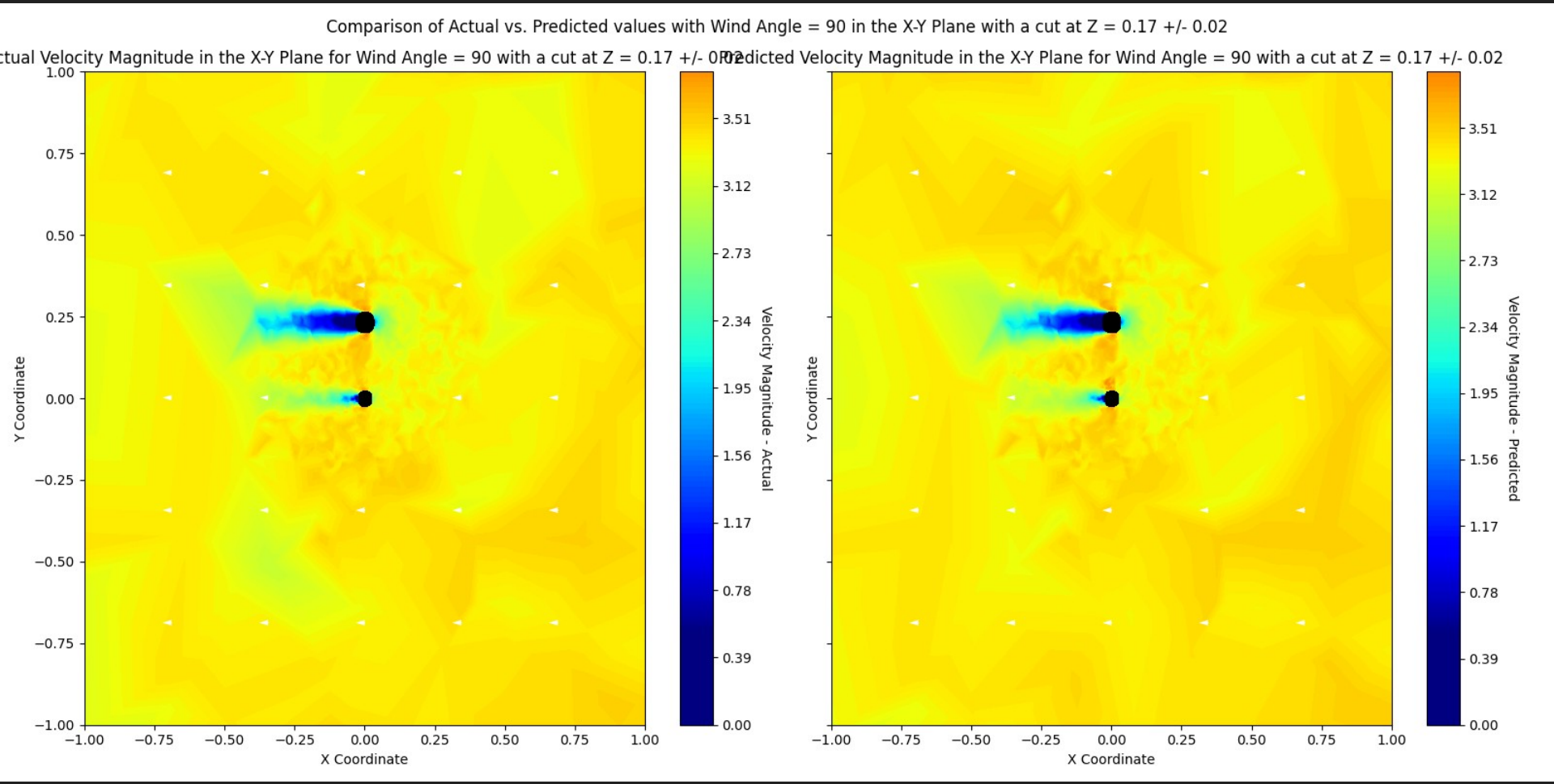


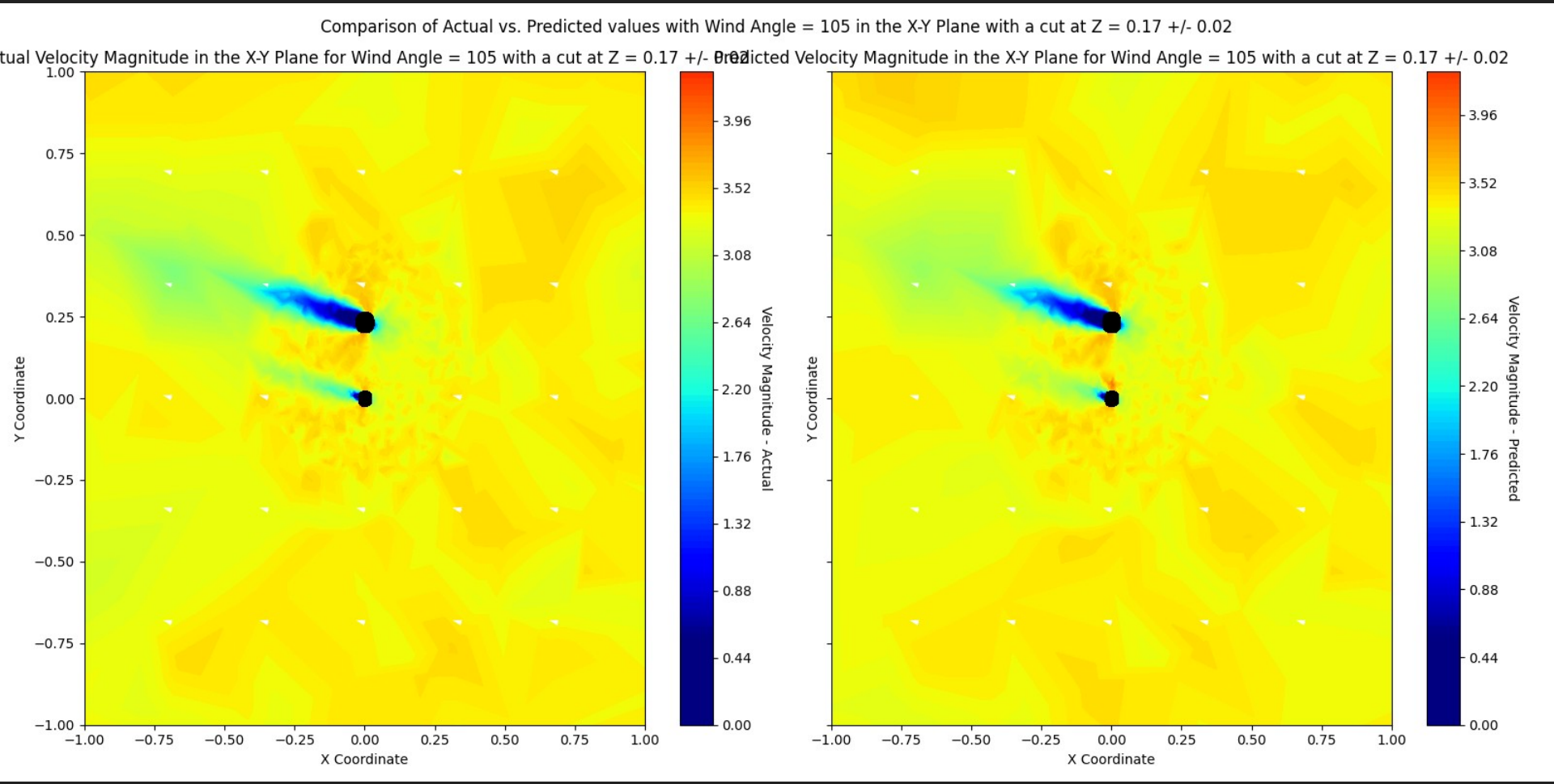
Comparison of Actual vs. Predicted values with Wind Angle = 45 in the X-Y Plane with a cut at Z = 0.17 +/- 0.02



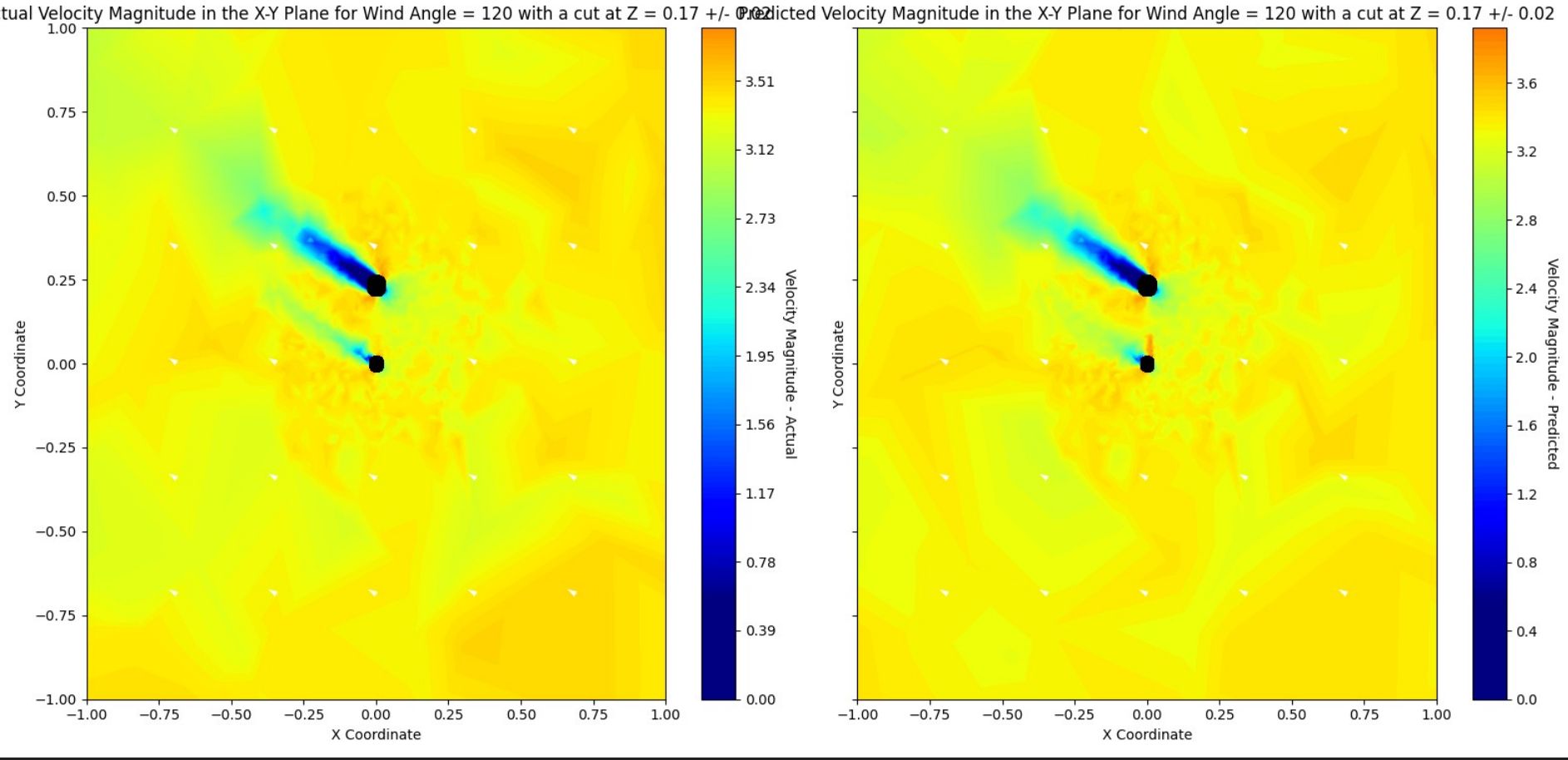

Comparison of Actual vs. Predicted values with Wind Angle = 60 in the X-Y Plane with a cut at Z = 0.17 +/- 0.02
ctual Velocity Magnitude in the X-Y Plane for Wind Angle = 60 with a cut at Z = 0.17 +/- 0.02
Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 60 with a cut at Z = 0.17 +/- 0.02
Y Coordinate
X Coordinate
Velocity Magnitude - Actual
Velocity Magnitude - Predicted
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
3.51
3.12
2.73
2.34
1.95
1.56
1.17
0.78
0.39
0.00

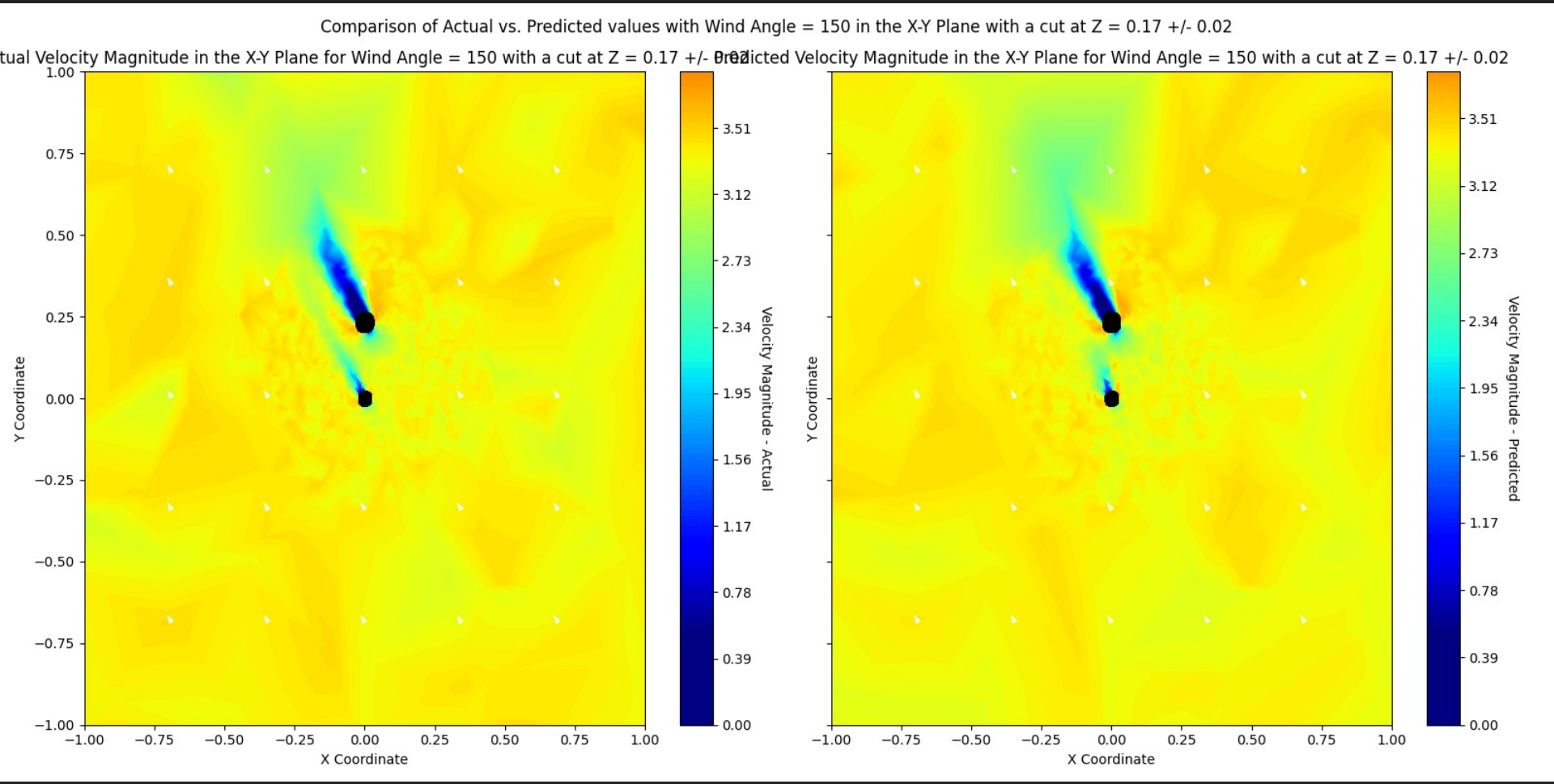

Comparison of Actual vs. Predicted values with Wind Angle = 75 in the X-Y Plane with a cut at Z = 0.17 +/- 0.02
ctual Velocity Magnitude in the X-Y Plane for Wind Angle = 75 with a cut at Z = 0.17 +/- 0.02
Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 75 with a cut at Z = 0.17 +/- 0.02
Y Coordinate
X Coordinate
Velocity Magnitude - Actual
Velocity Magnitude - Predicted
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
3.51
3.12
2.73
2.34
1.95
1.56
1.17
0.78
0.39
0.00

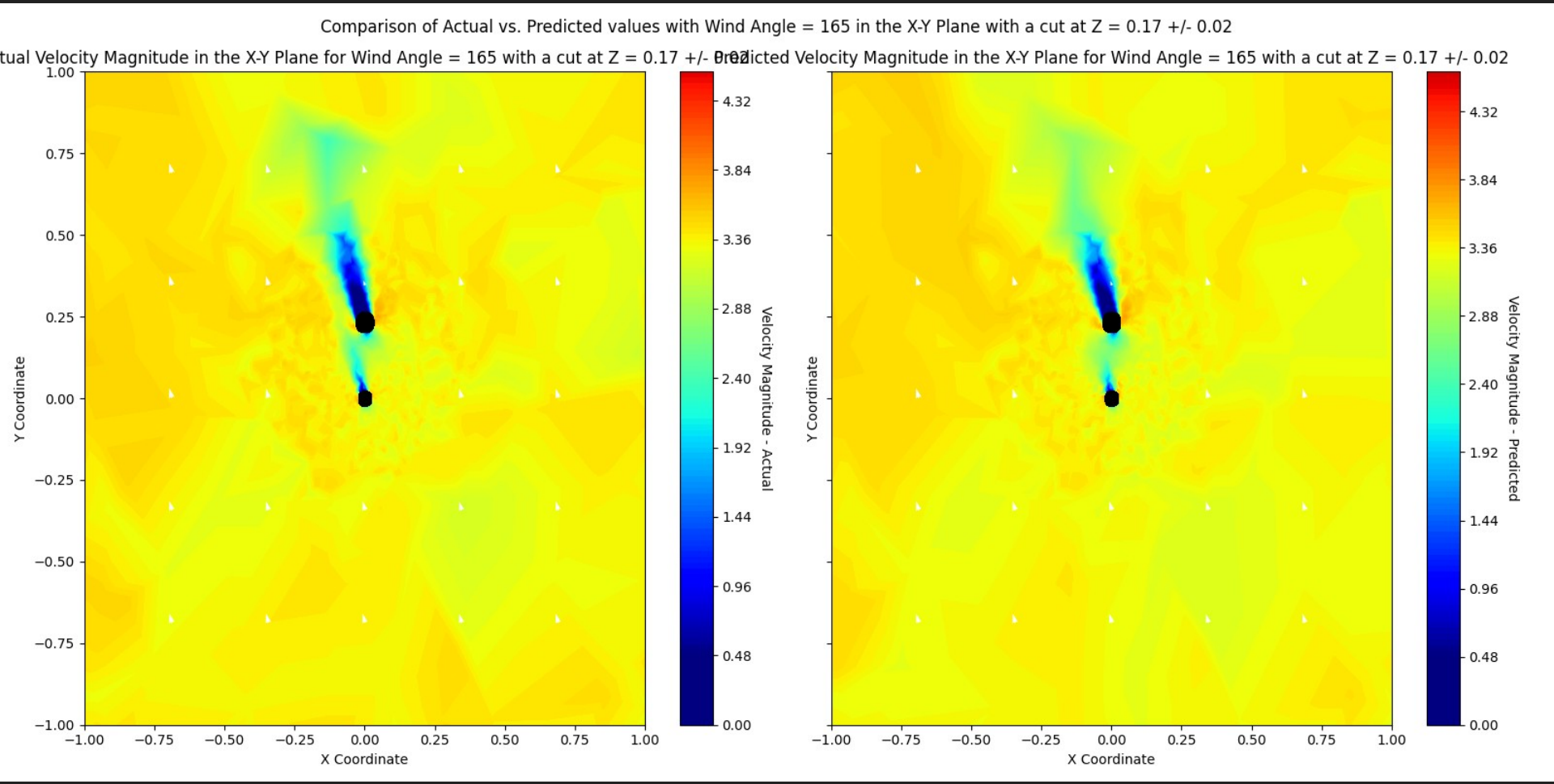

Comparison of Actual vs. Predicted values with Wind Angle = 90 in the X-Y Plane with a cut at Z = 0.17 +/- 0.02
ctual Velocity Magnitude in the X-Y Plane for Wind Angle = 90 with a cut at Z = 0.17 +/- 0.02
Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 90 with a cut at Z = 0.17 +/- 0.02
Y Coordinate
X Coordinate
Velocity Magnitude - Actual
Velocity Magnitude - Predicted
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
3.51
3.12
2.73
2.34
1.95
1.56
1.17
0.78
0.39
0.00


Comparison of Actual vs. Predicted values with Wind Angle = 105 in the X-Y Plane with a cut at Z = 0.17 +/- 0.02
tual Velocity Magnitude in the X-Y Plane for Wind Angle = 105 with a cut at Z = 0.17 +/- 0.02
Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 105 with a cut at Z = 0.17 +/- 0.02
Y Coordinate
X Coordinate
Velocity Magnitude - Actual
Velocity Magnitude - Predicted
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
3.96
3.52
3.08
2.64
2.20
1.76
1.32
0.88
0.44
0.00

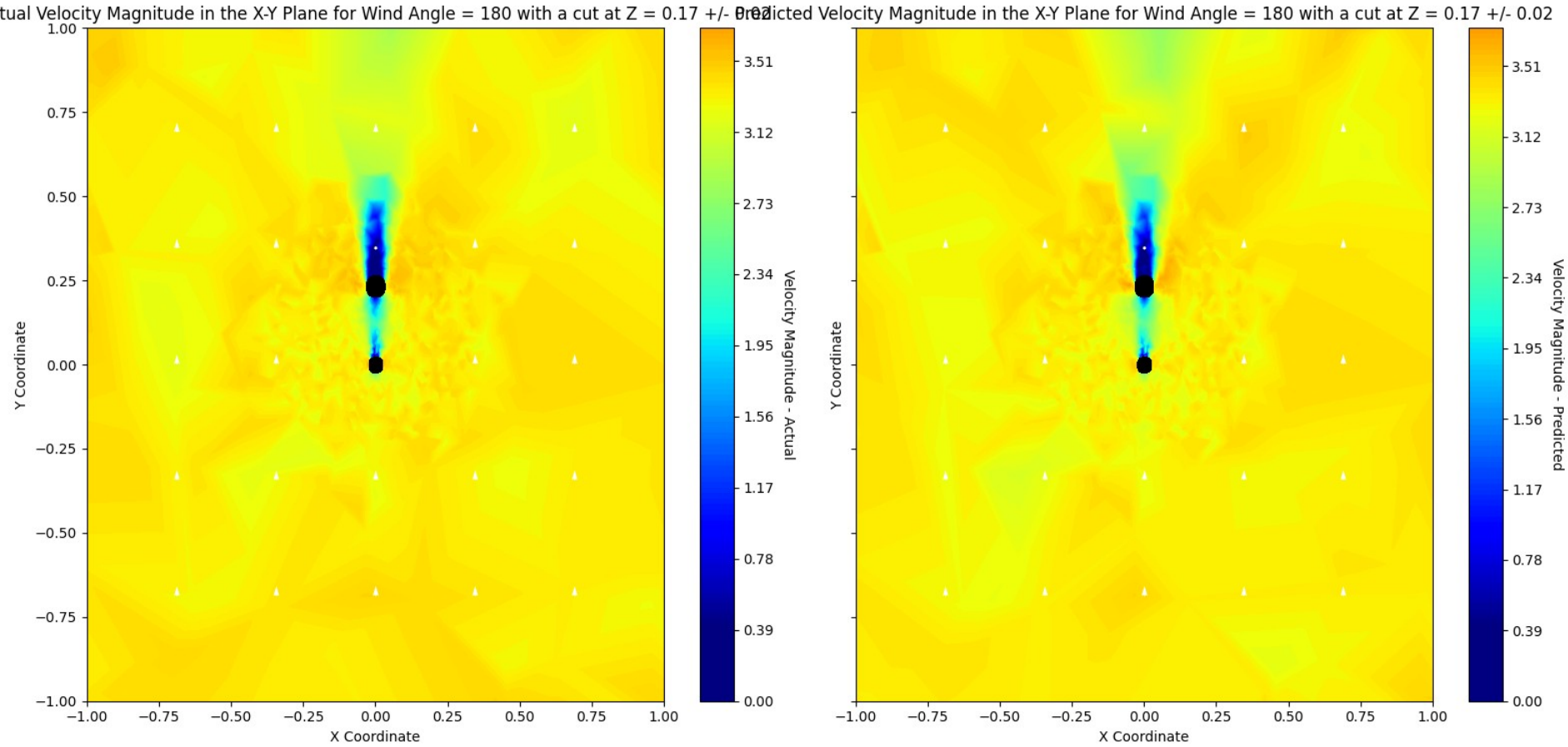
Comparison of Actual vs. Predicted values with Wind Angle = 120 in the X-Y Plane with a cut at Z = 0.17 +/- 0.02




Comparison of Actual vs. Predicted values with Wind Angle = 150 in the X-Y Plane with a cut at Z = 0.17 +/- 0.02
tual Velocity Magnitude in the X-Y Plane for Wind Angle = 150 with a cut at Z = 0.17 +/- 0.02
Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 150 with a cut at Z = 0.17 +/- 0.02
Y Coordinate
X Coordinate
Velocity Magnitude - Actual
Velocity Magnitude - Predicted
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
3.51
3.12
2.73
2.34
1.95
1.56
1.17
0.78
0.39
0.00


Comparison of Actual vs. Predicted values with Wind Angle = 165 in the X-Y Plane with a cut at Z = 0.17 +/- 0.02
tual Velocity Magnitude in the X-Y Plane for Wind Angle = 165 with a cut at Z = 0.17 +/- 0.02
Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 165 with a cut at Z = 0.17 +/- 0.02
Y Coordinate
X Coordinate
Velocity Magnitude - Actual
Velocity Magnitude - Predicted
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
4.32
3.84
3.36
2.88
2.40
1.92
1.44
0.96
0.48
0.00

Comparison of Actual vs. Predicted values with Wind Angle = 180 in the X-Y Plane with a cut at Z = 0.17 +/- 0.02



Progress so far - Data Loss Only
Standard Normal Scalar – ELU Activation
(Adam Optimizer)

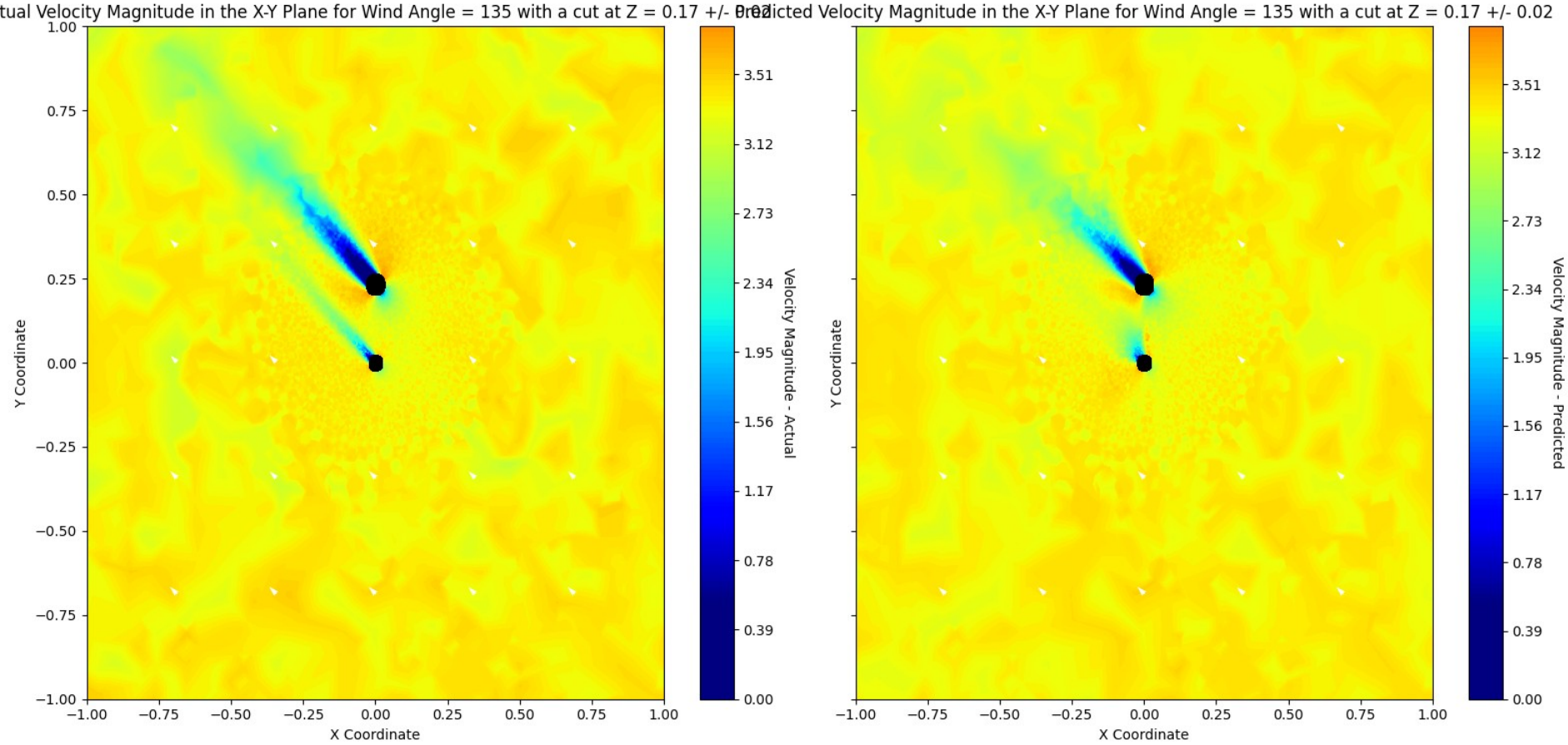
Threshold = SMA 1E-5 (2740 Epochs, not completed), GPU Laptop

Scripts v5 – PREDICTING

Progress so far - Data Loss Only, Standard Normal Scalar, ELU Activation, Adam Optimizer
Threshold = SMA 1E-5 (2740 Epochs, not completed), GPU Laptop
Predicting Results – Metrics (Angle = 135)

Variable	MSE	RMSE	MAE	R2
Pressure	0.09402374	0.30663291	0.23739974	0.94437658
Velocity:0	0.00923516	0.09609976	0.07006339	0.99093905
Velocity:1	0.01571656	0.12536572	0.09390356	0.98472693
Velocity:2	0.00059523	0.02439723	0.01218803	0.98180522
TurbVisc	0.09235305	0.30389644	0.22898648	0.99932703

Comparison of Actual vs. Predicted values with Wind Angle = 135 in the X-Y Plane with a cut at Z = 0.17 +/- 0.02

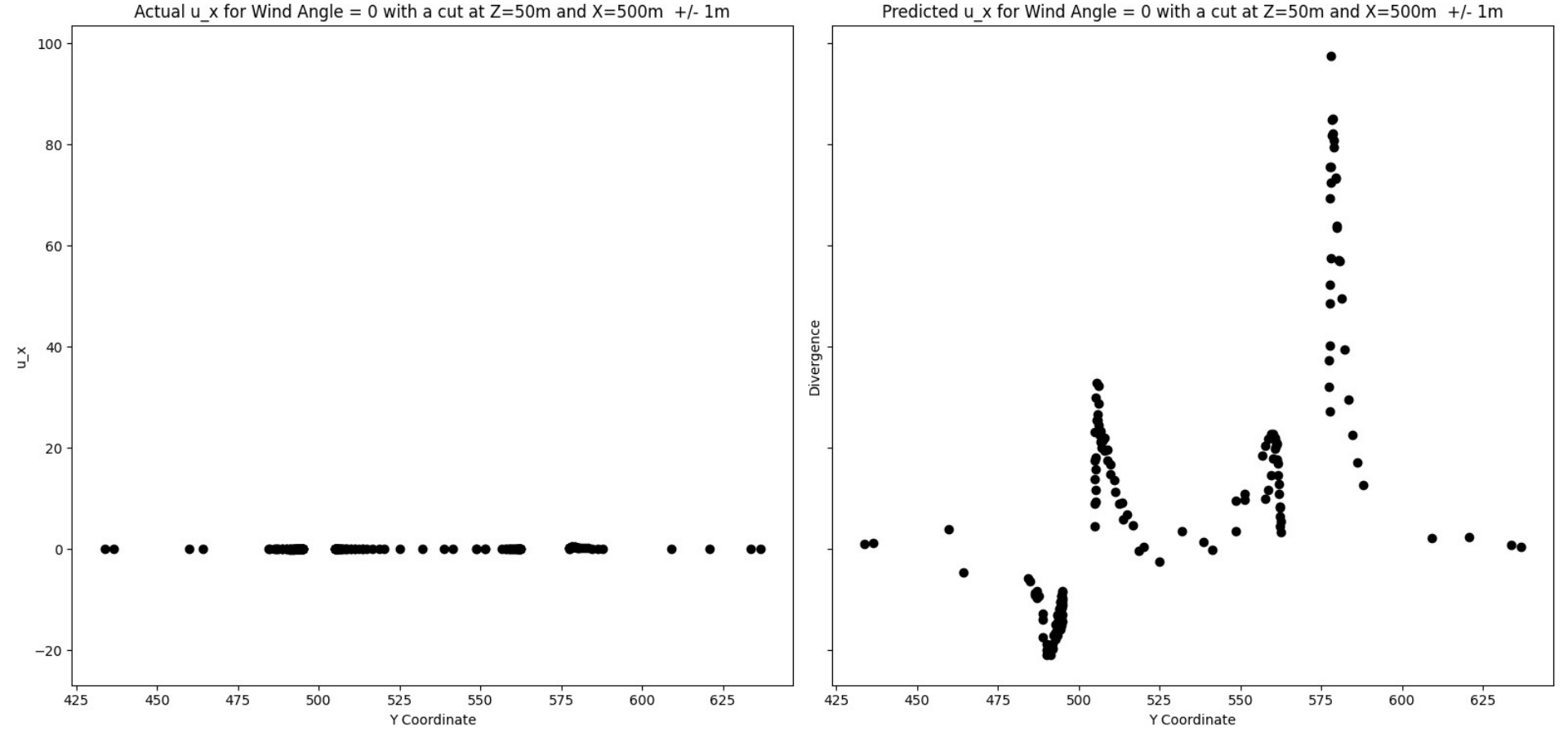


Progress so far - Data Loss Only
Standard Normal Scalar – ELU Activation
(Adam Optimizer)

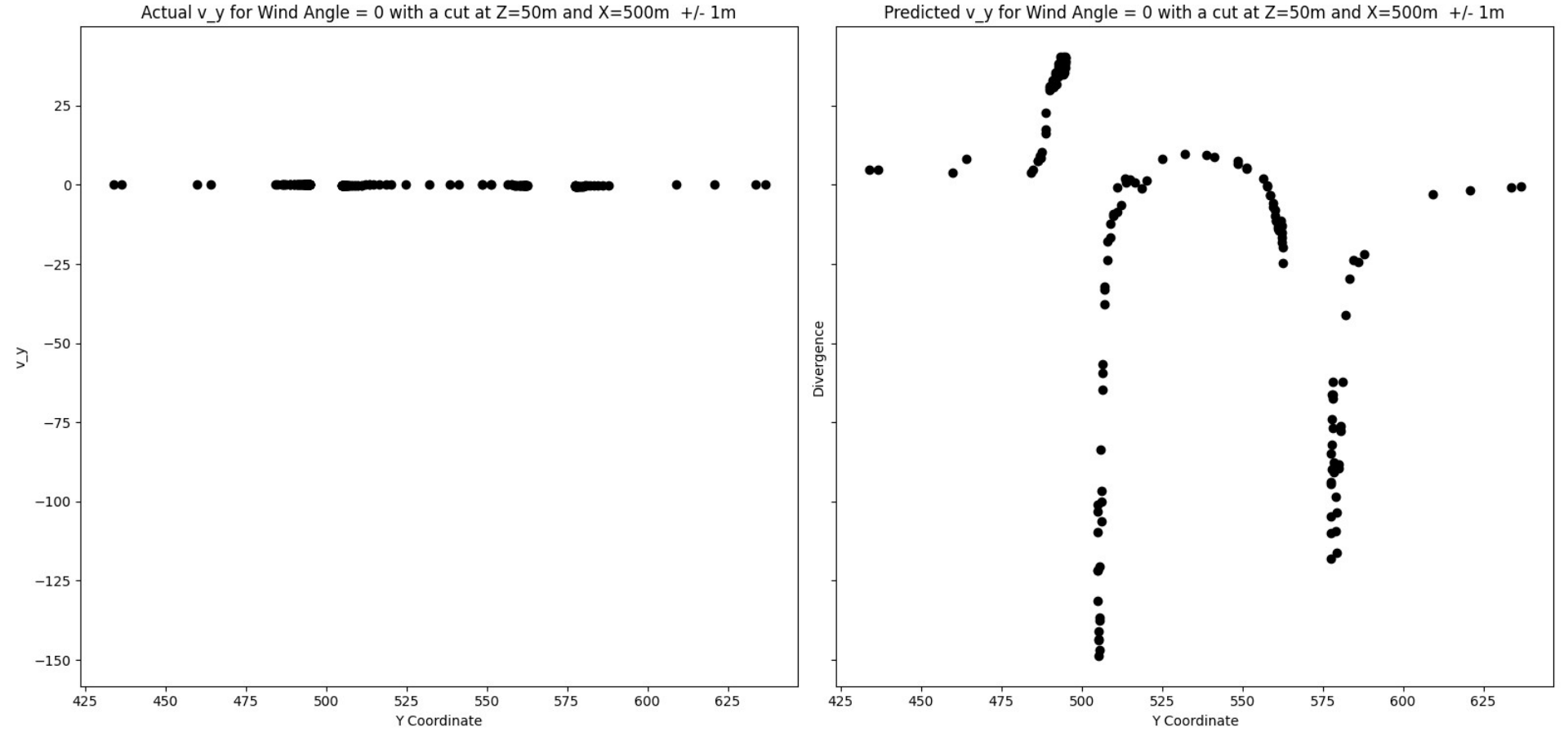
Threshold = SMA 1E-5 (2740 Epochs, not completed), GPU Laptop

Scripts v5 – DIVERGENCE

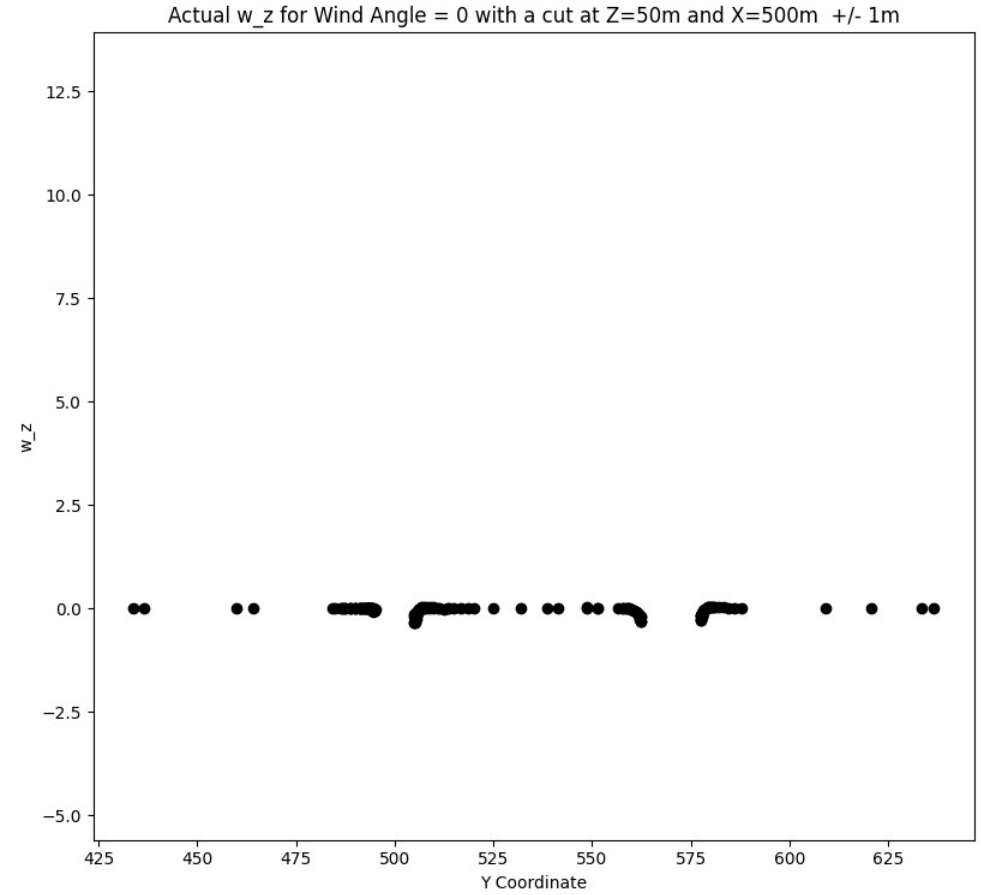
Comparison of Actual vs. Predicted values with Wind Angle = 0

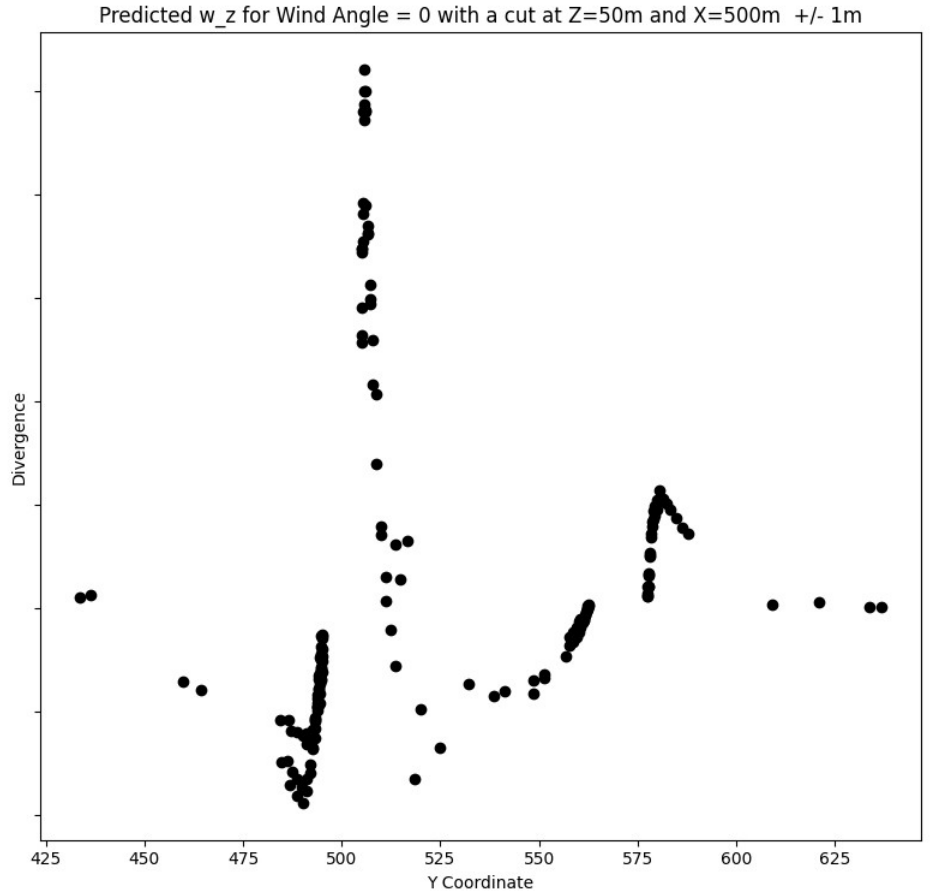


Comparison of Actual vs. Predicted values with Wind Angle = 0

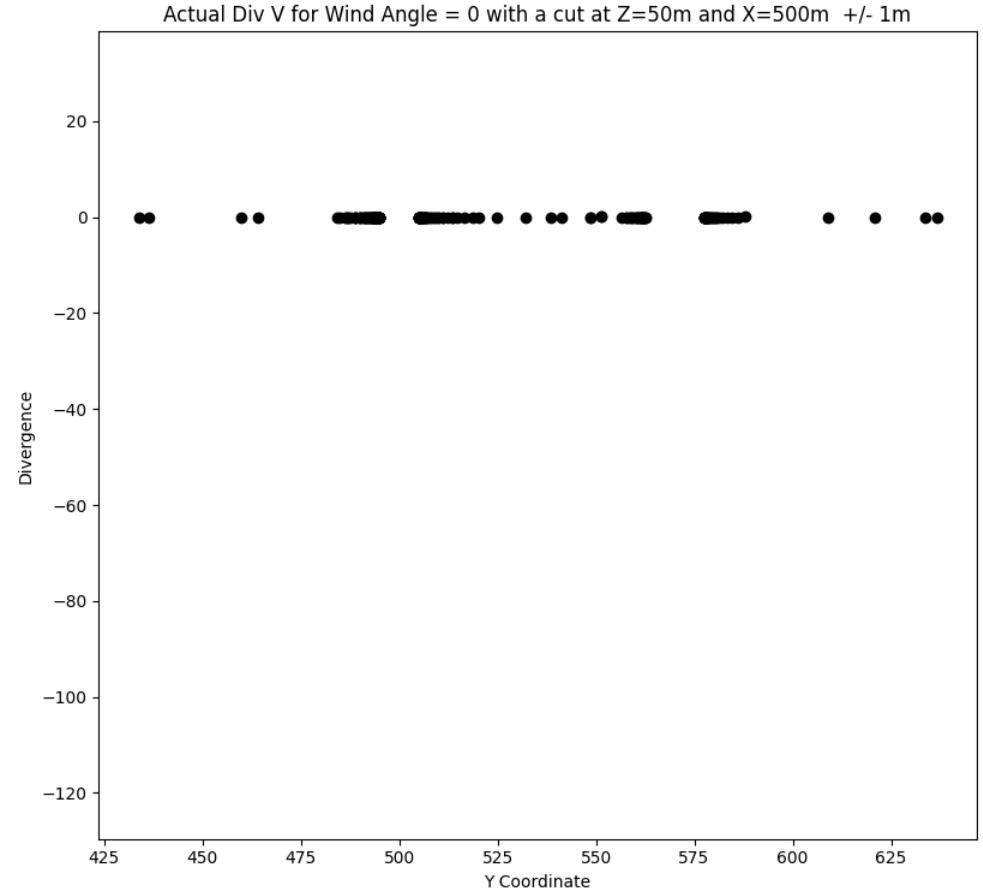


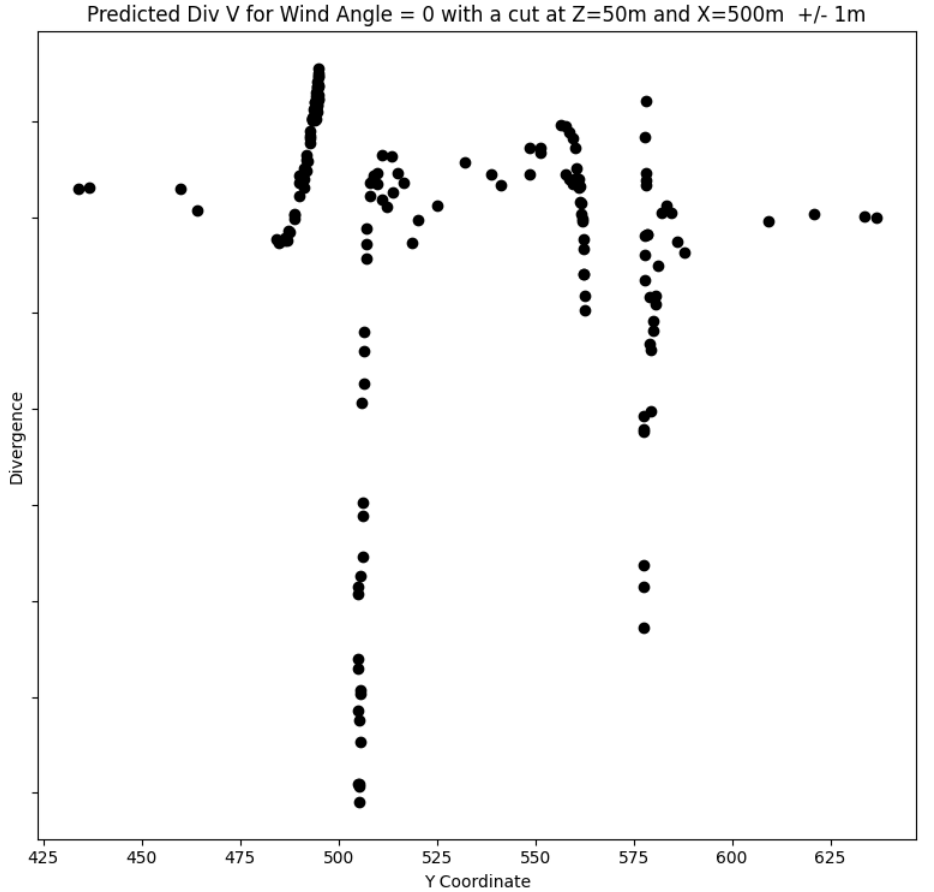
Comparison of Actual vs. Predicted values with Wind Angle = 0



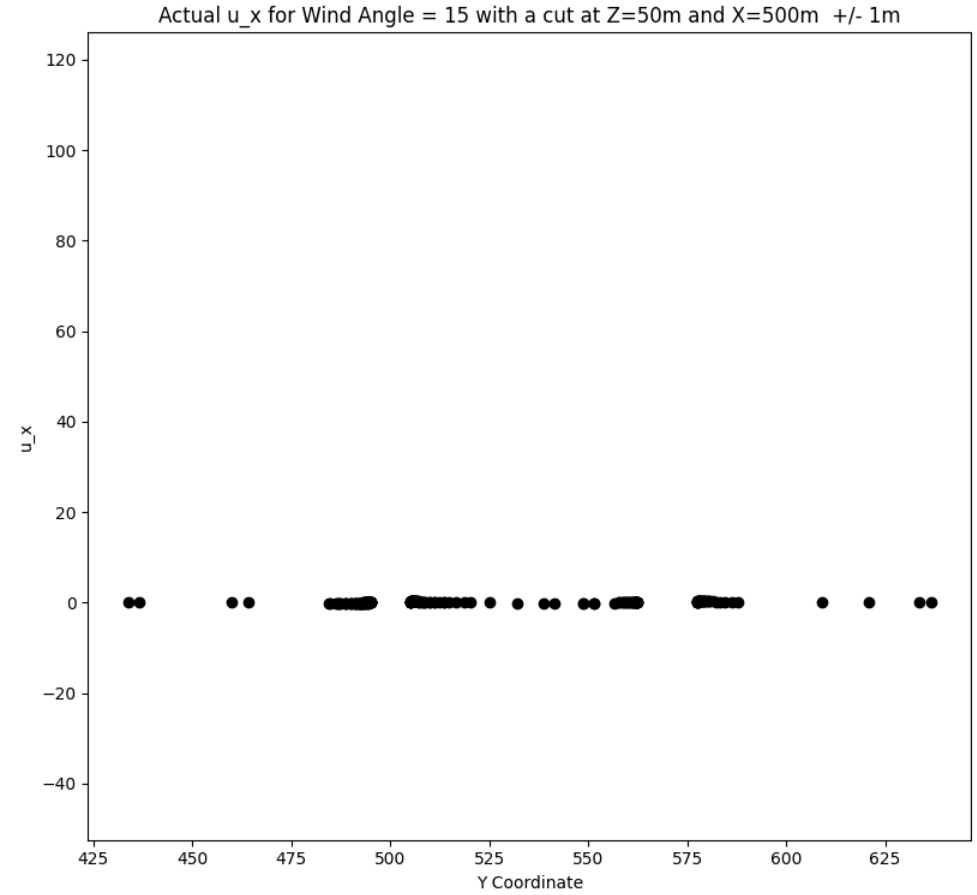


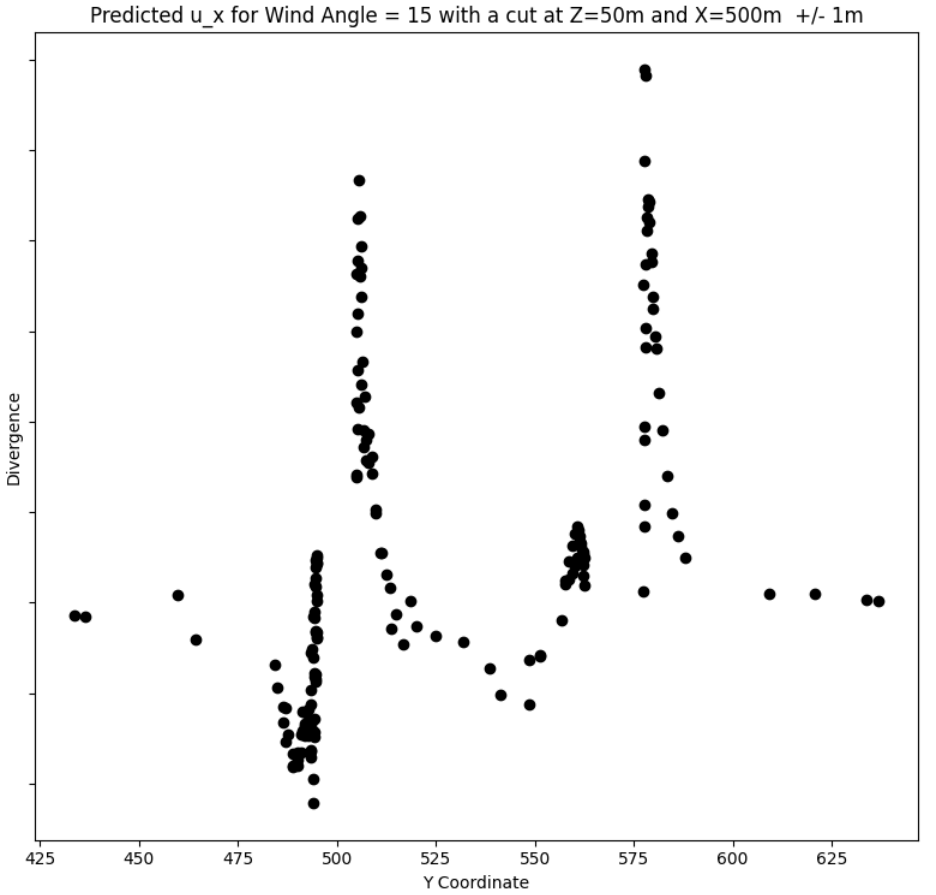
Comparison of Actual vs. Predicted values with Wind Angle = 0



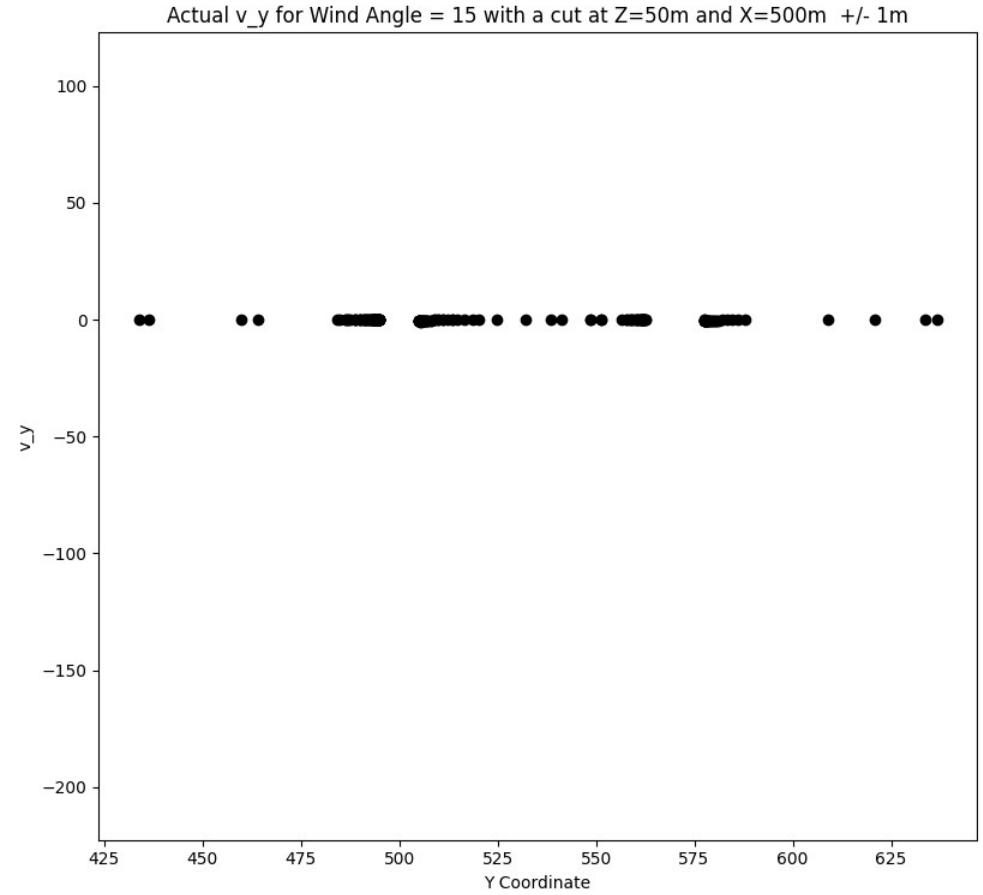


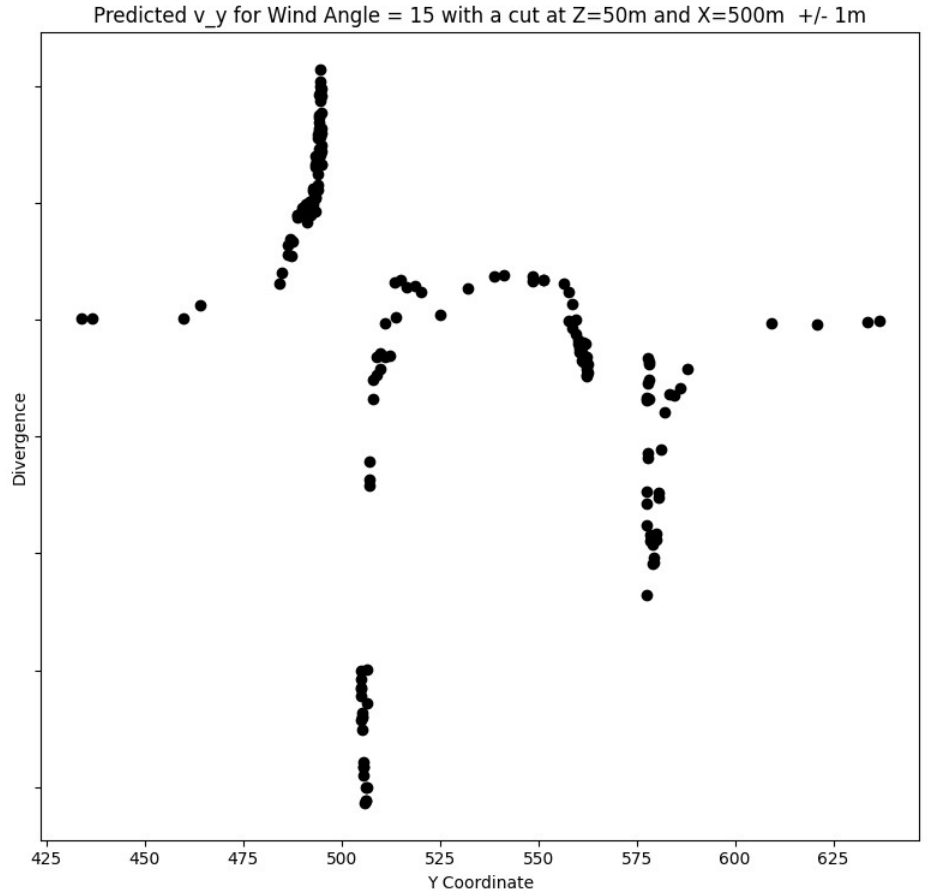
Comparison of Actual vs. Predicted values with Wind Angle = 15



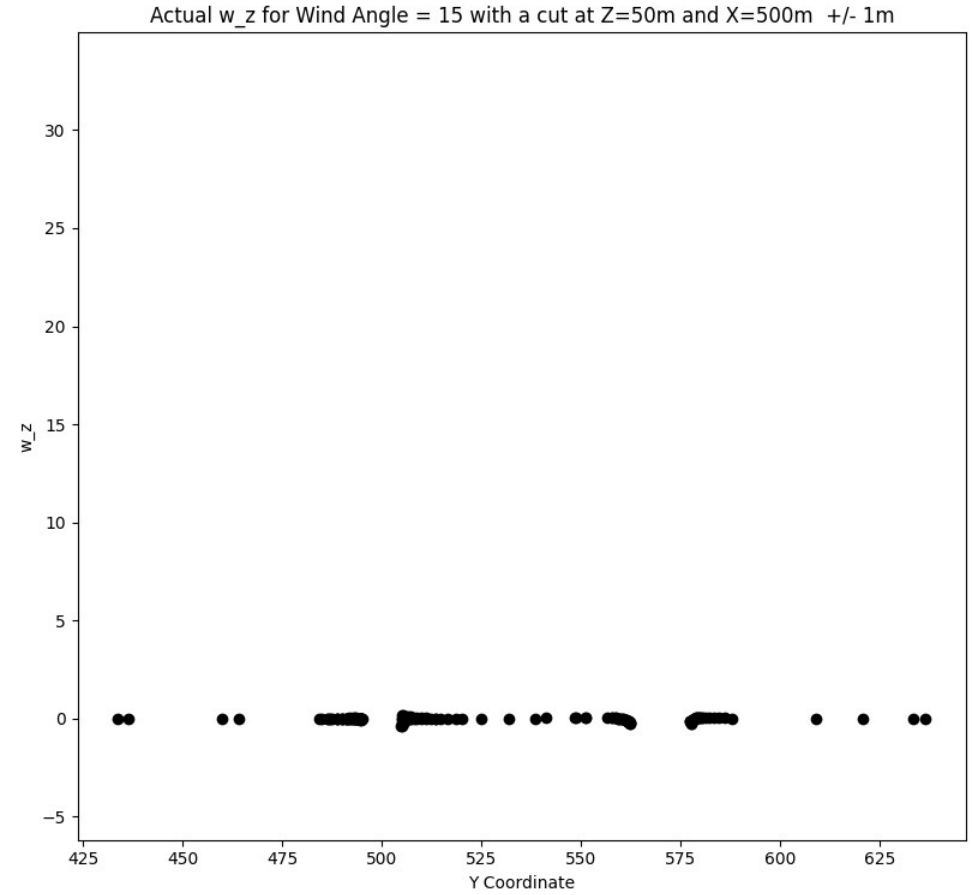


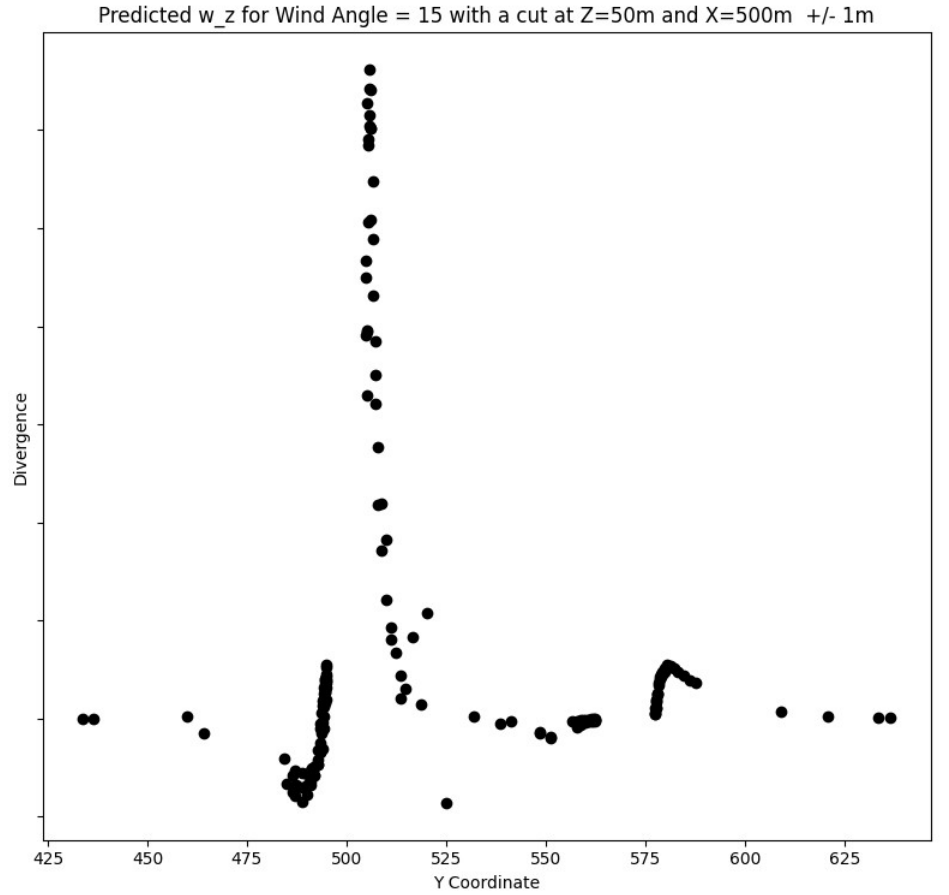
Comparison of Actual vs. Predicted values with Wind Angle = 15



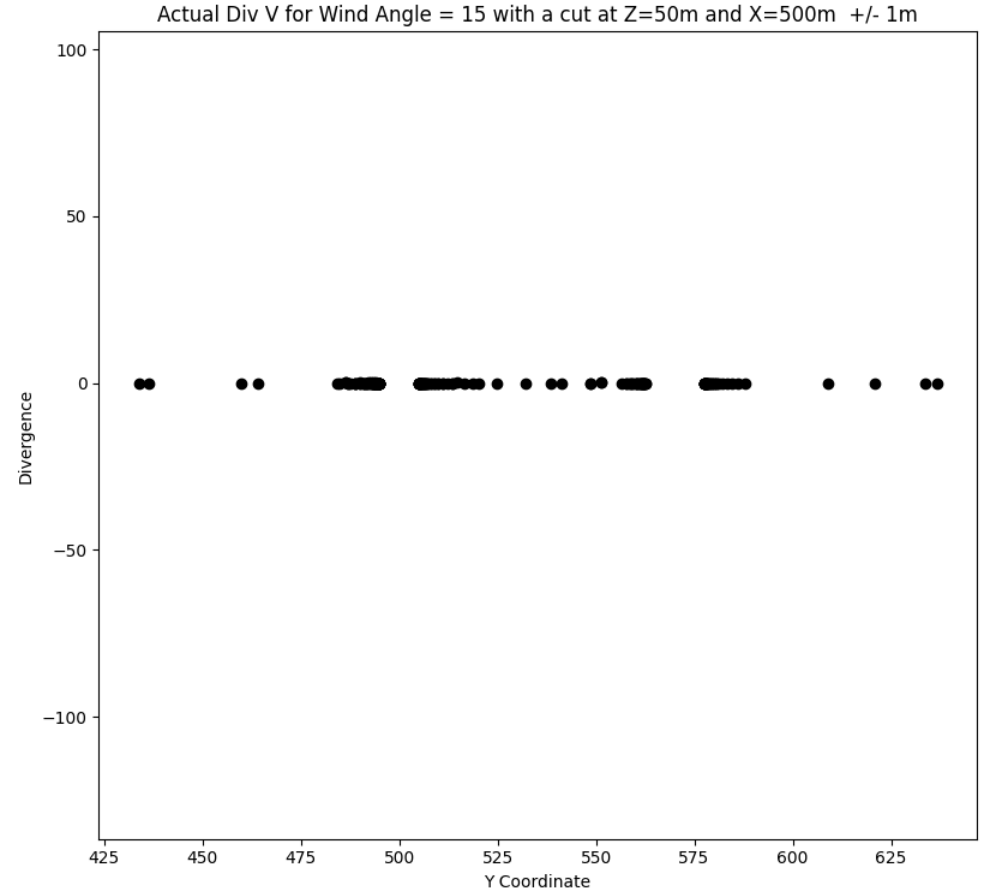


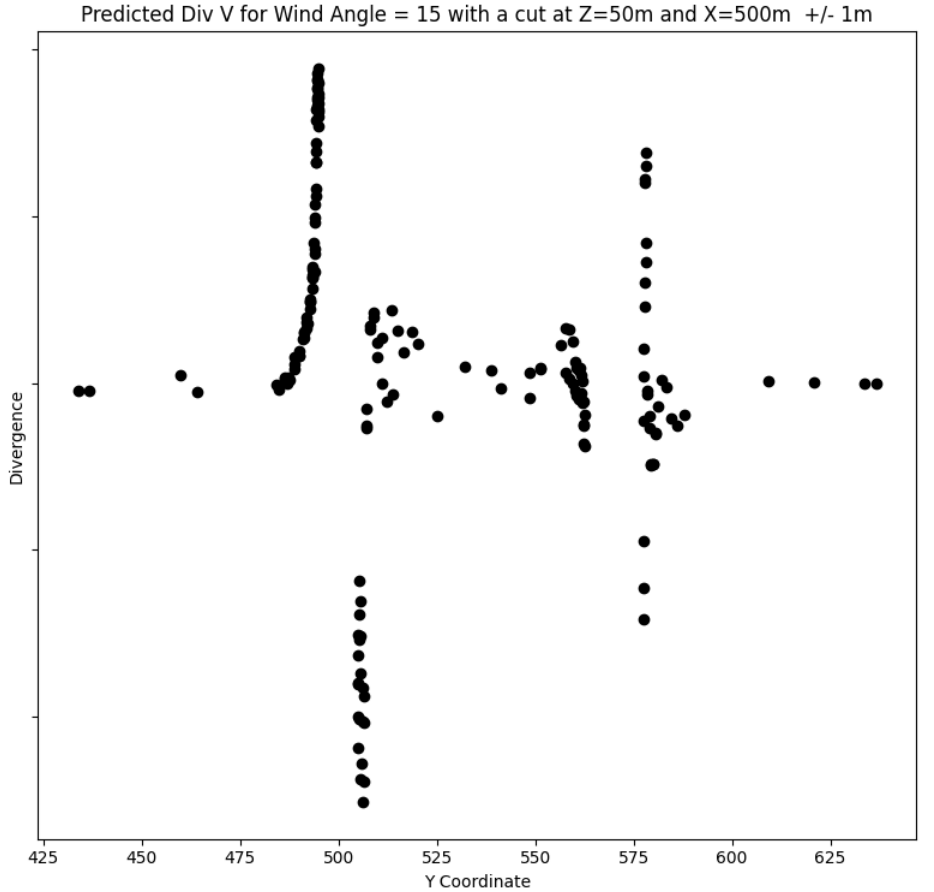
Comparison of Actual vs. Predicted values with Wind Angle = 15



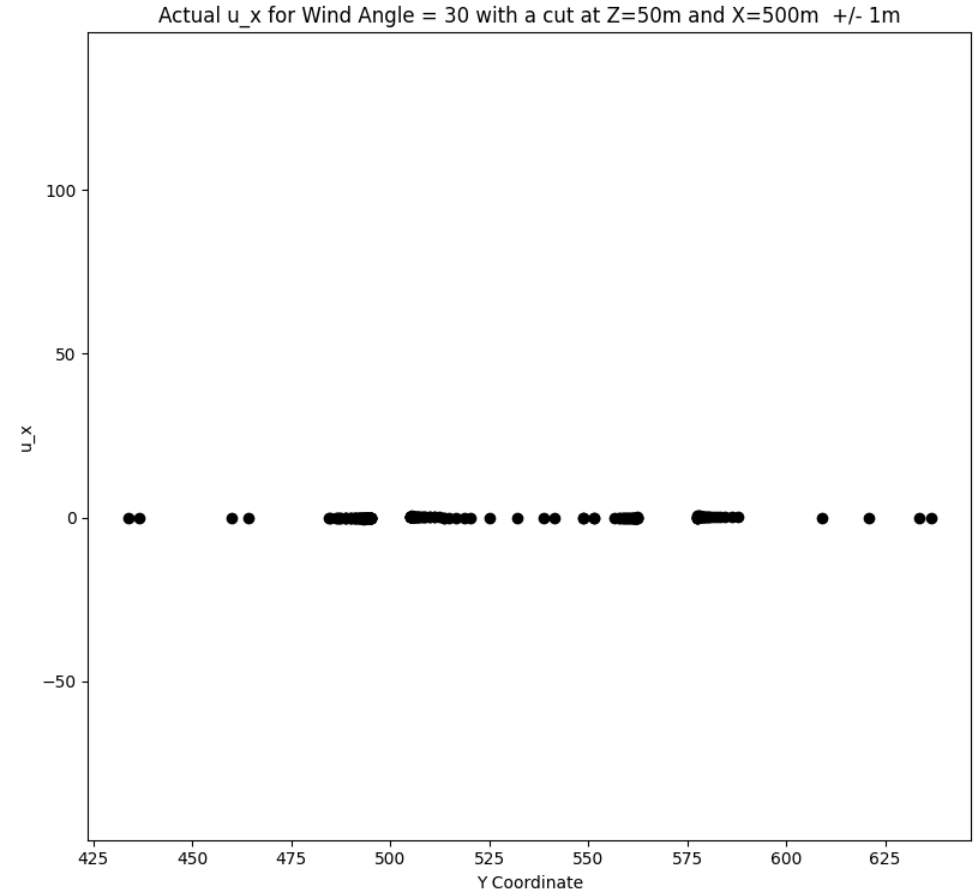


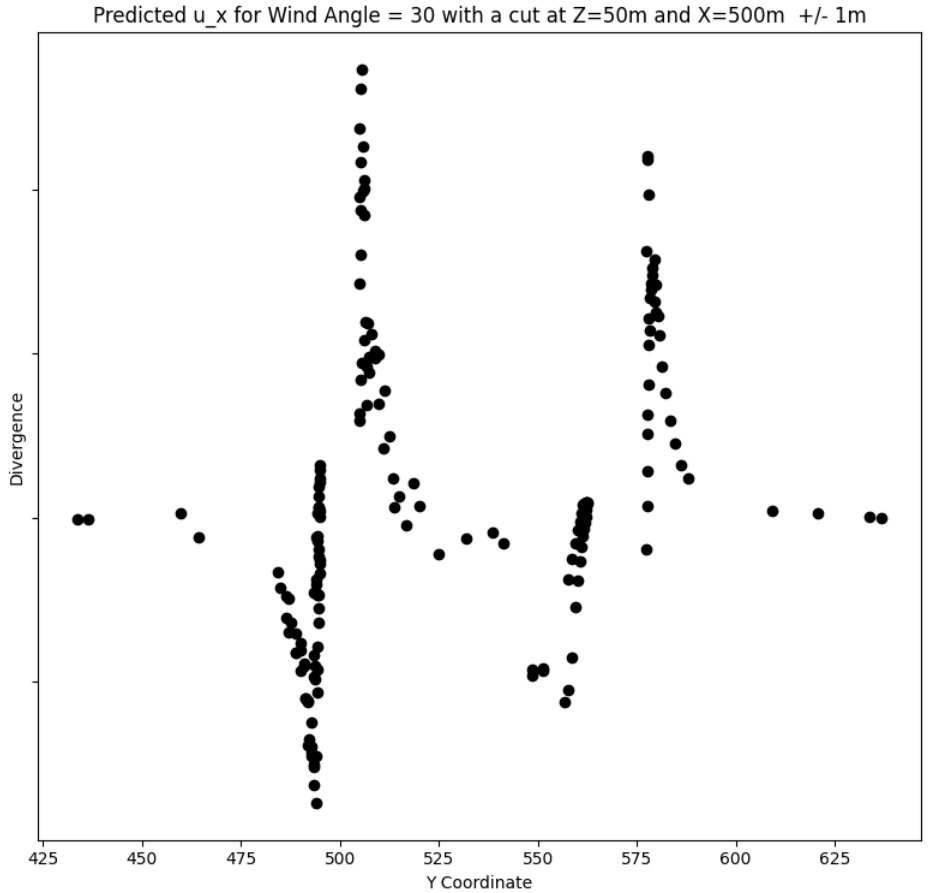
Comparison of Actual vs. Predicted values with Wind Angle = 15



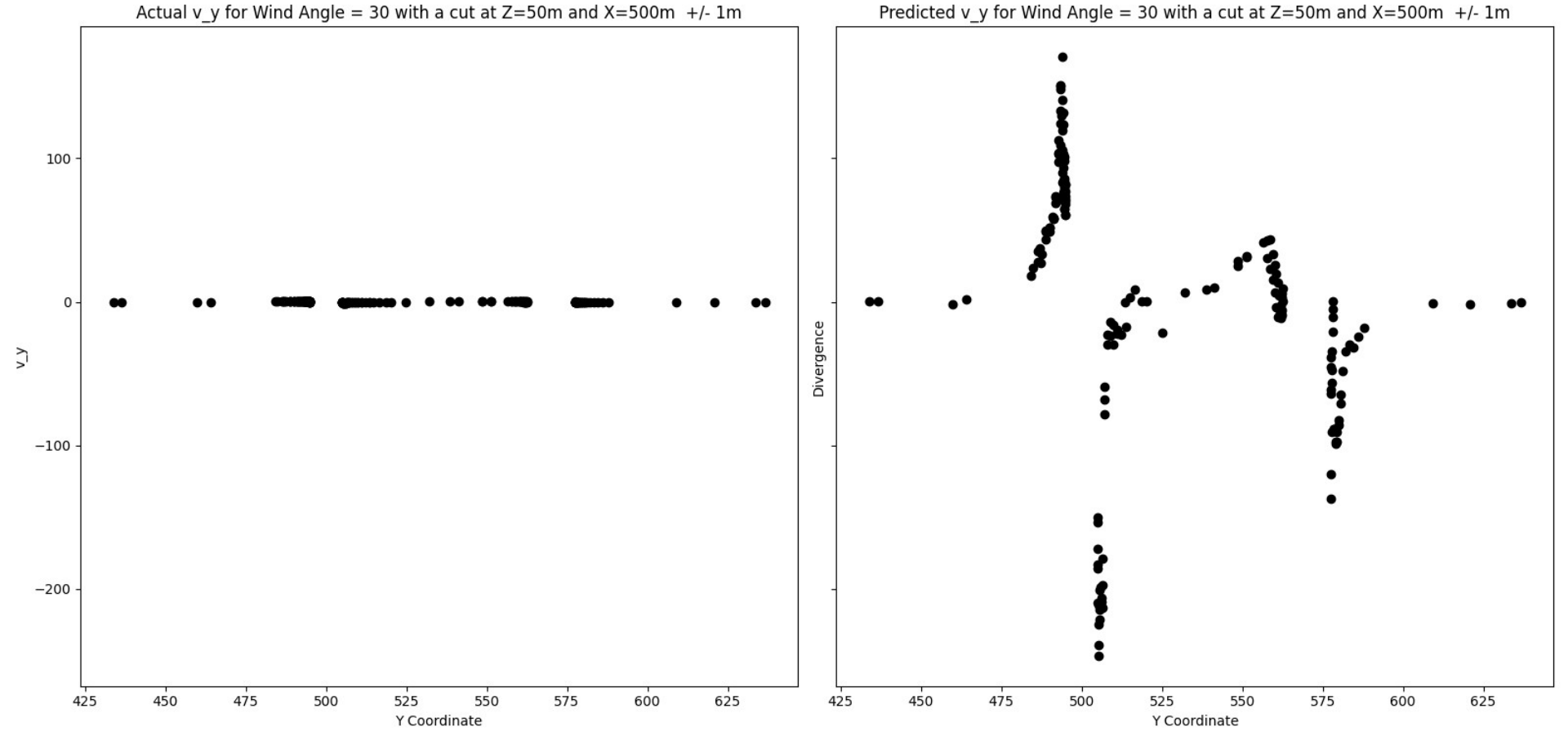


Comparison of Actual vs. Predicted values with Wind Angle = 30

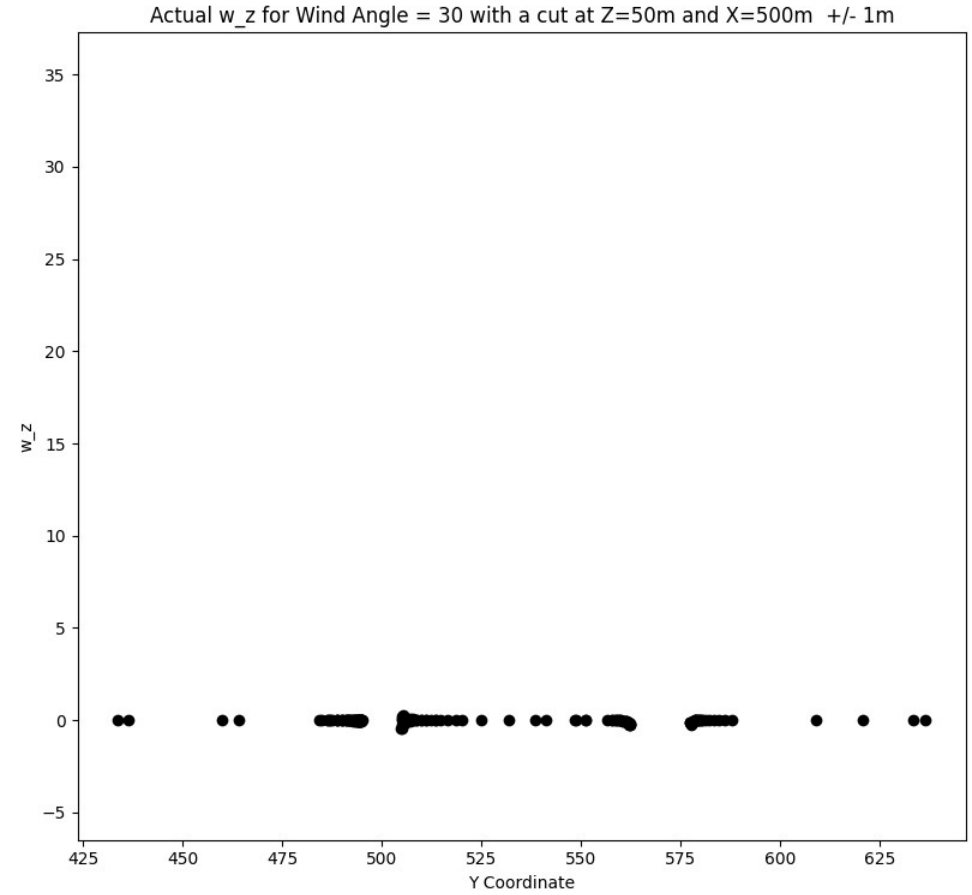


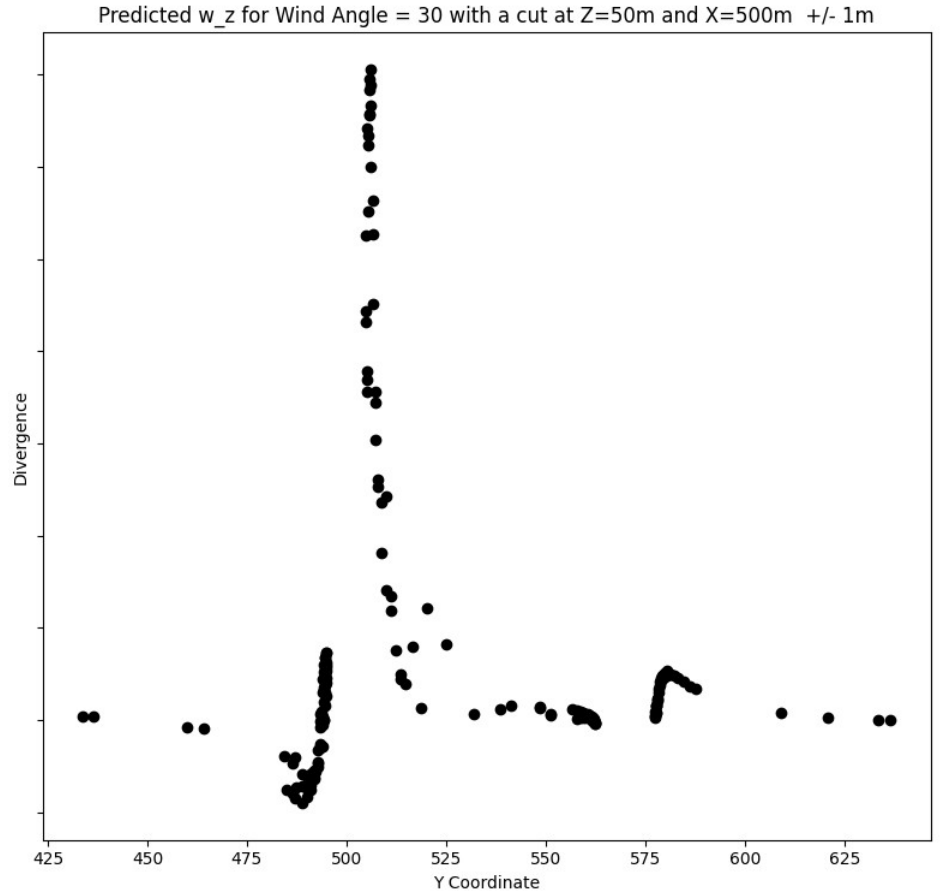


Comparison of Actual vs. Predicted values with Wind Angle = 30

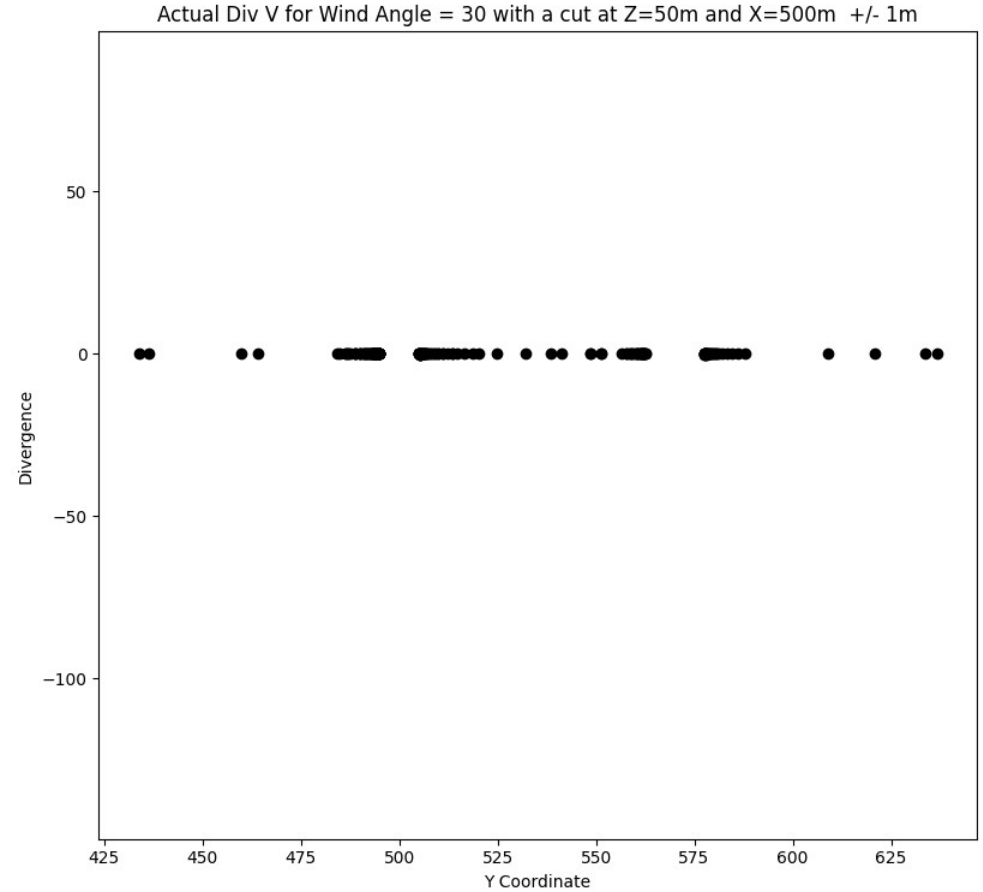


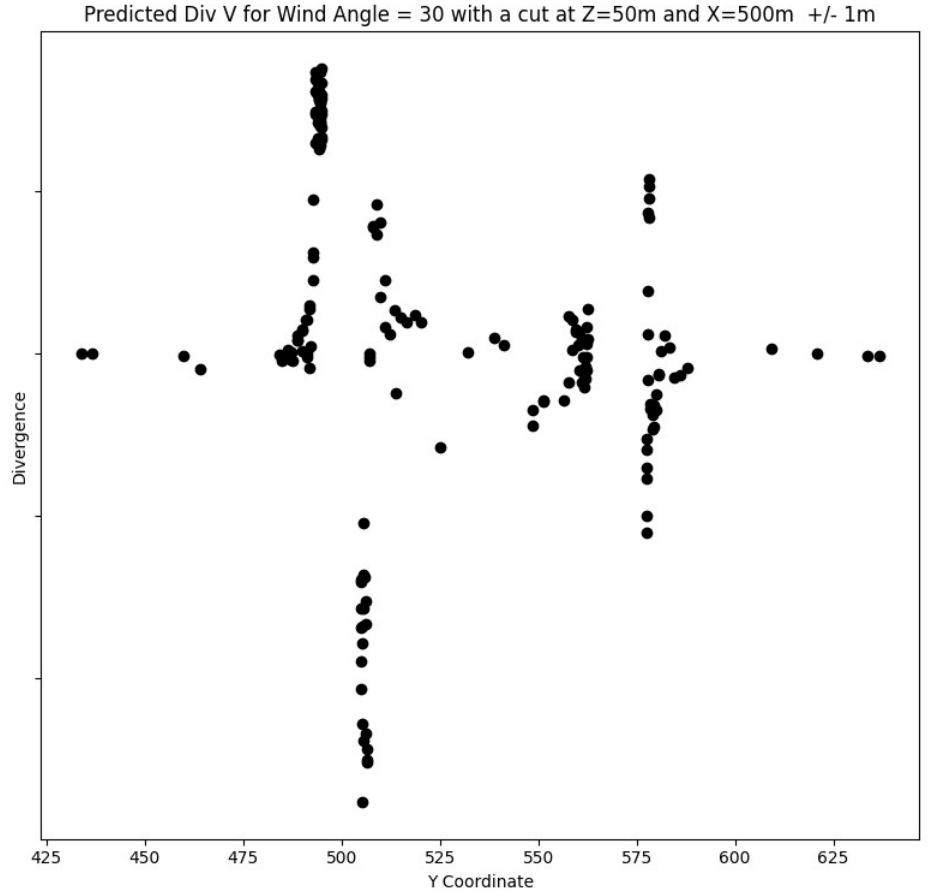
Comparison of Actual vs. Predicted values with Wind Angle = 30



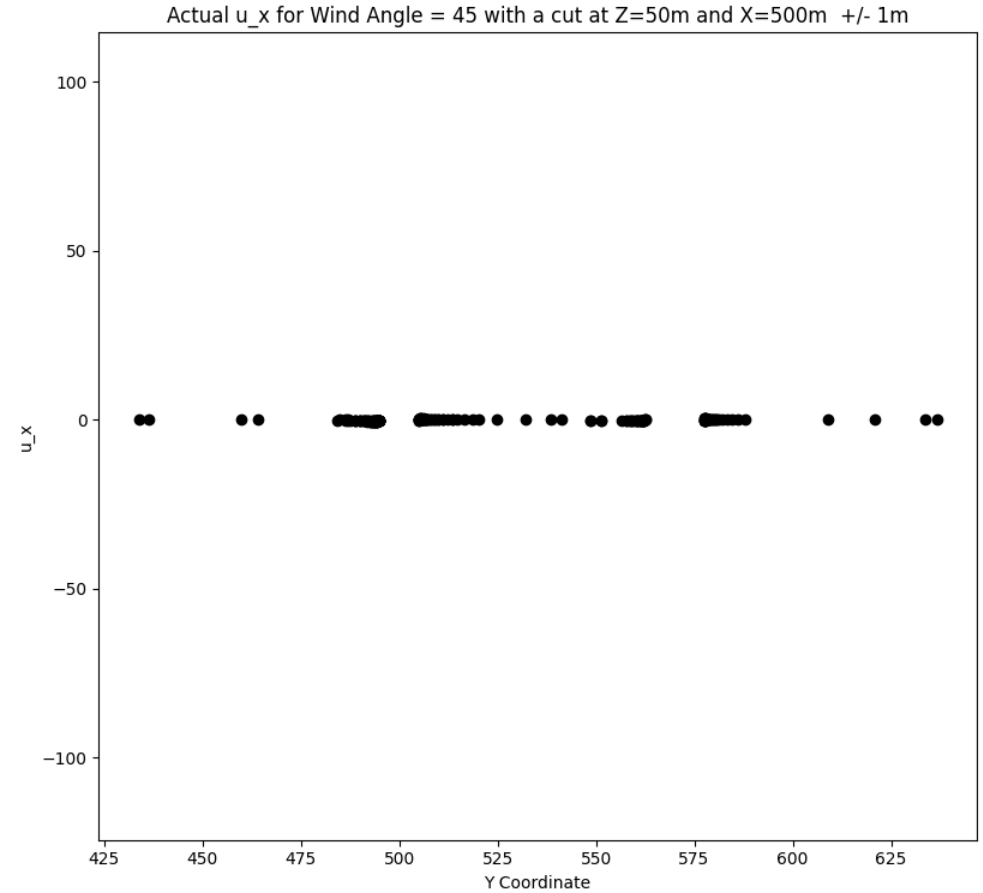


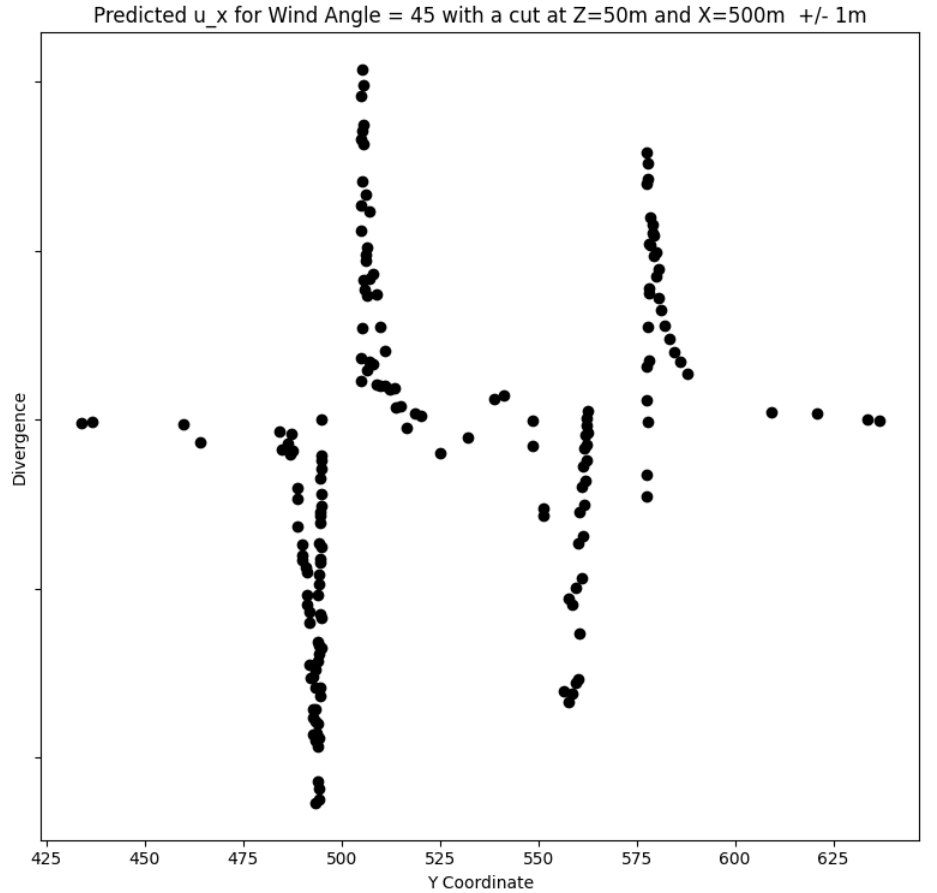
Comparison of Actual vs. Predicted values with Wind Angle = 30



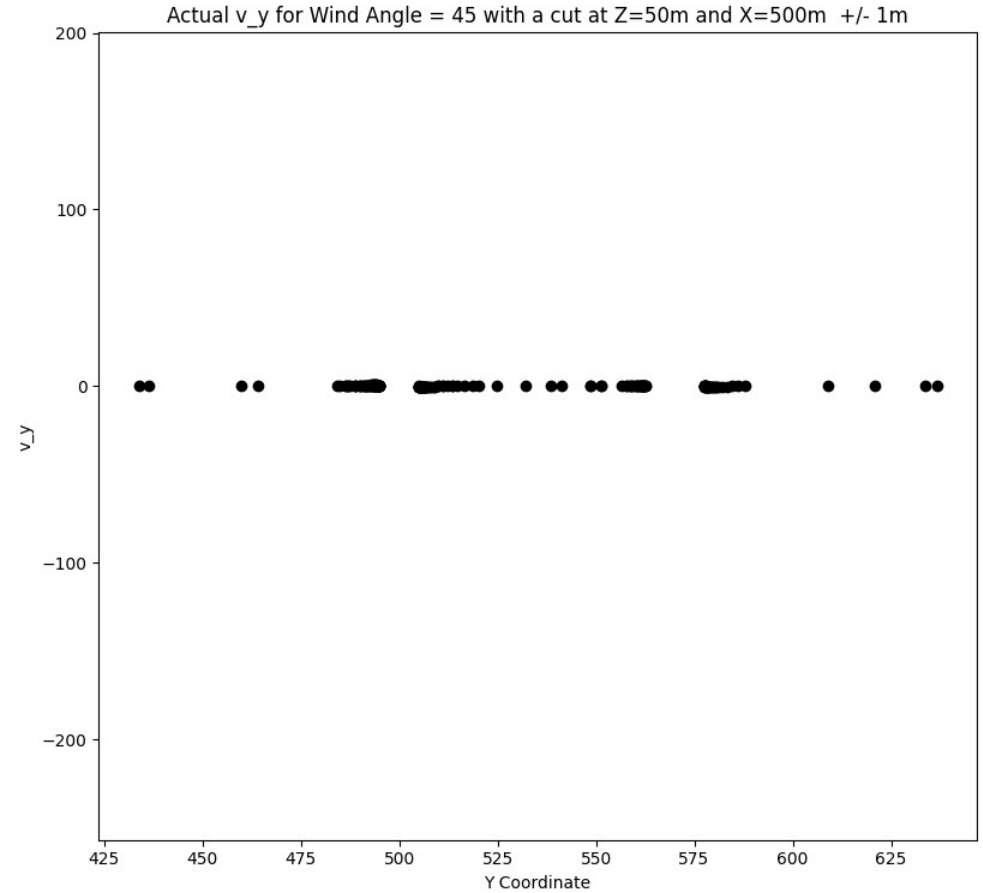


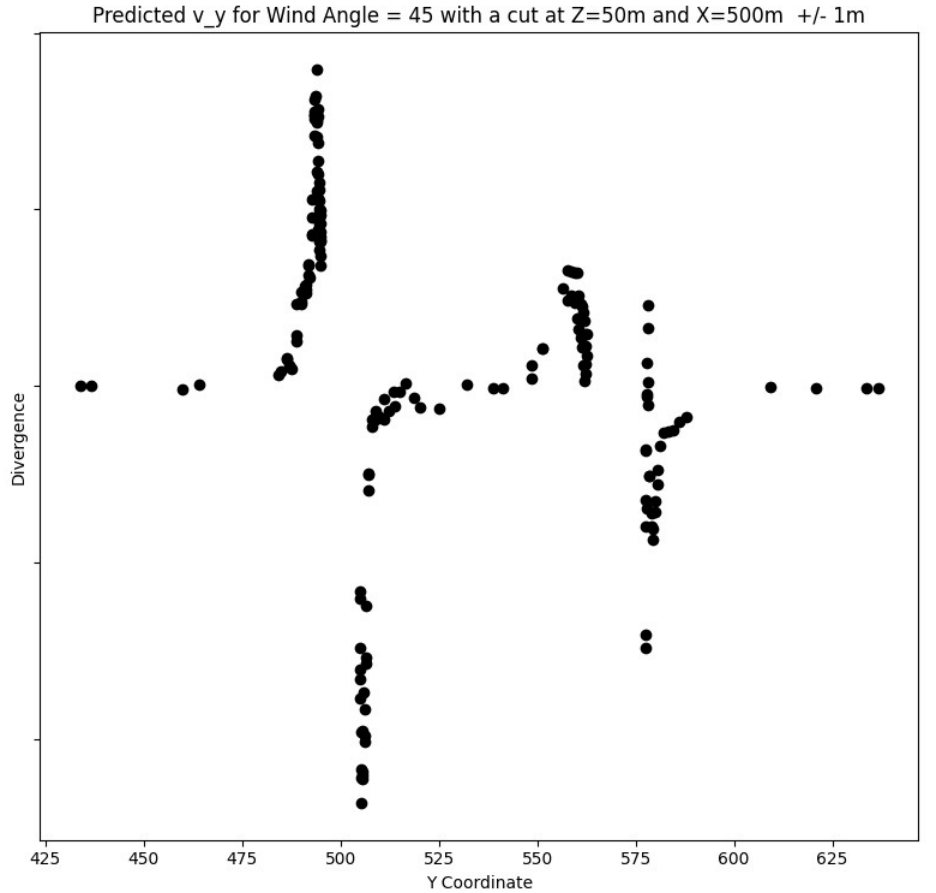
Comparison of Actual vs. Predicted values with Wind Angle = 45



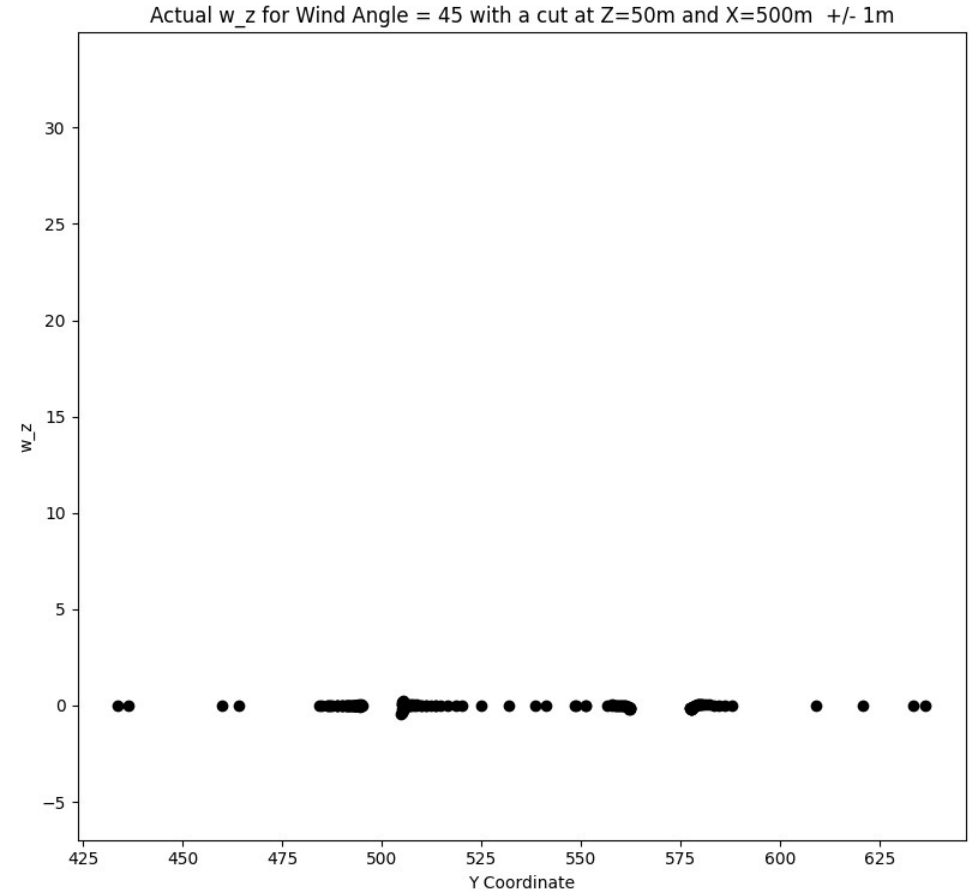


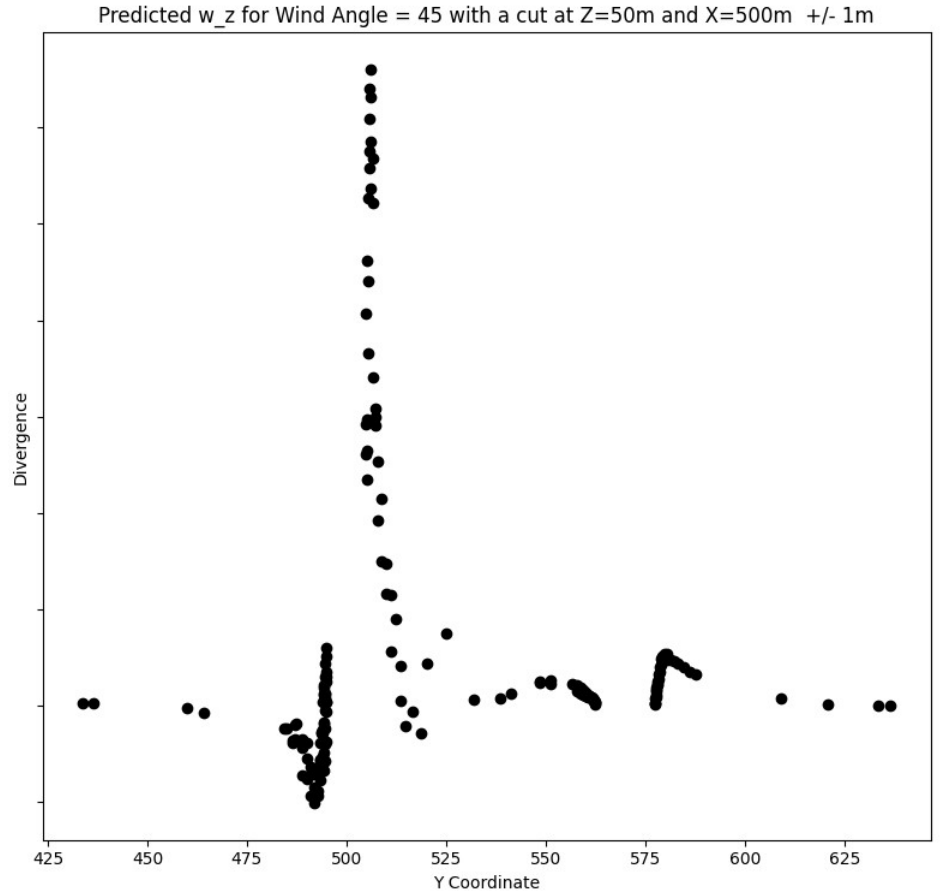
Comparison of Actual vs. Predicted values with Wind Angle = 45



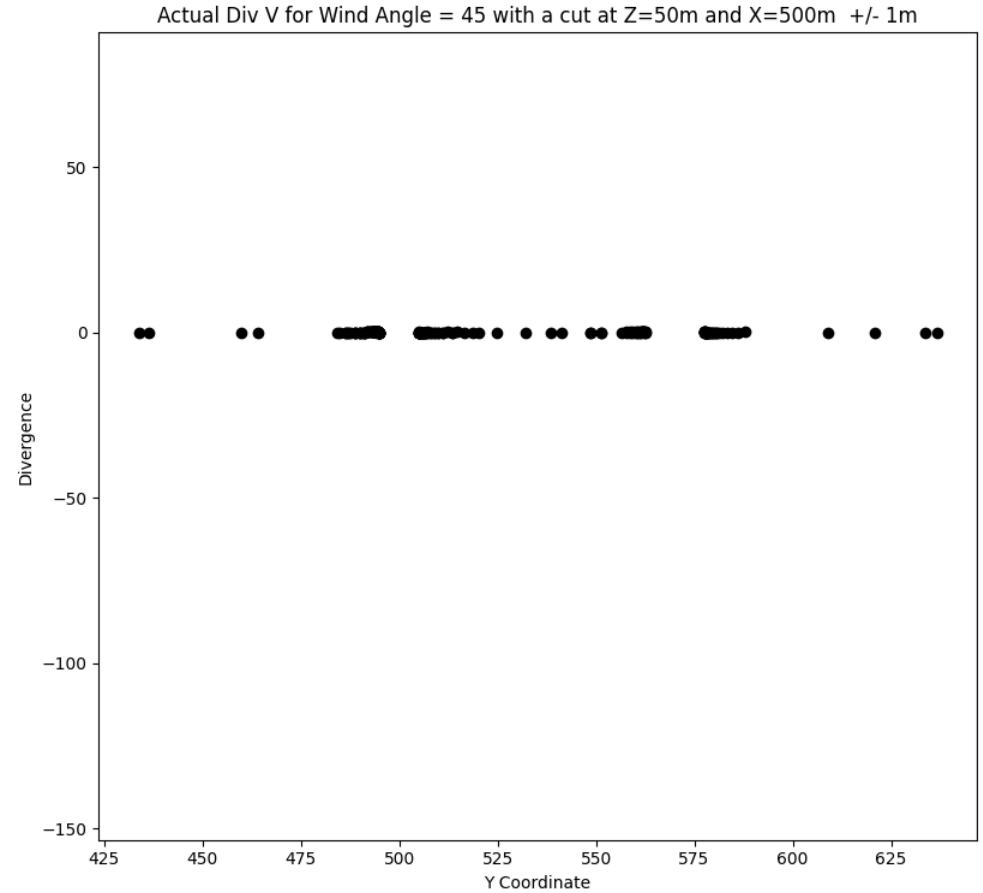


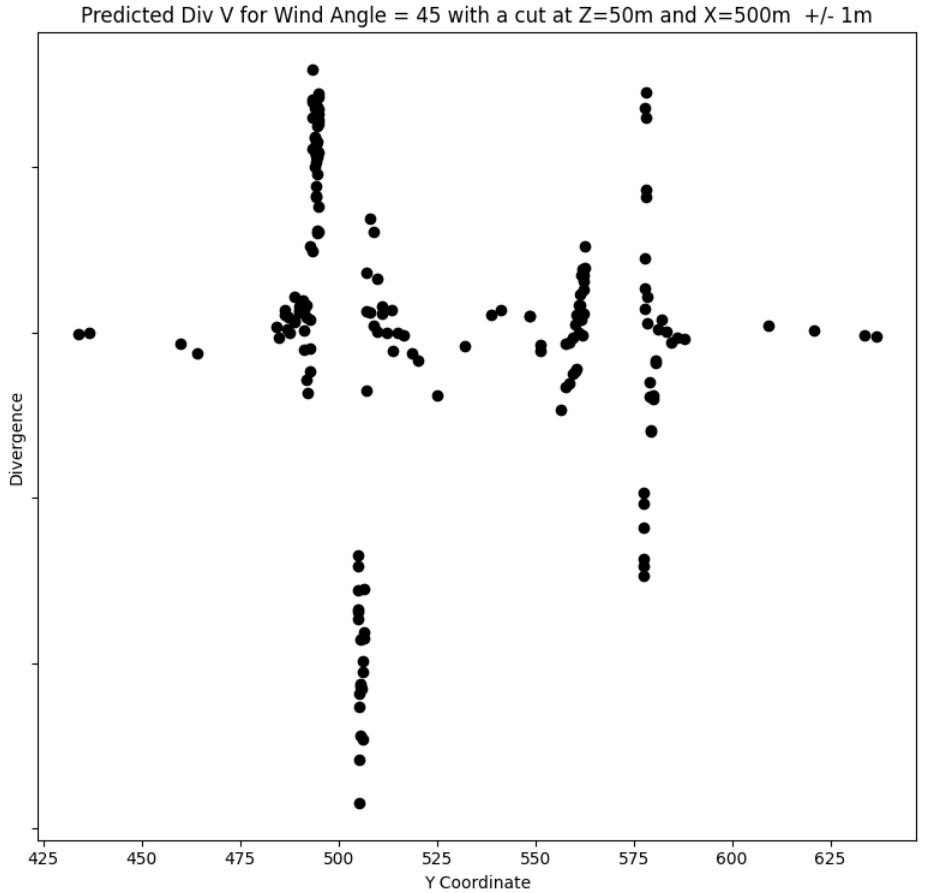
Comparison of Actual vs. Predicted values with Wind Angle = 45



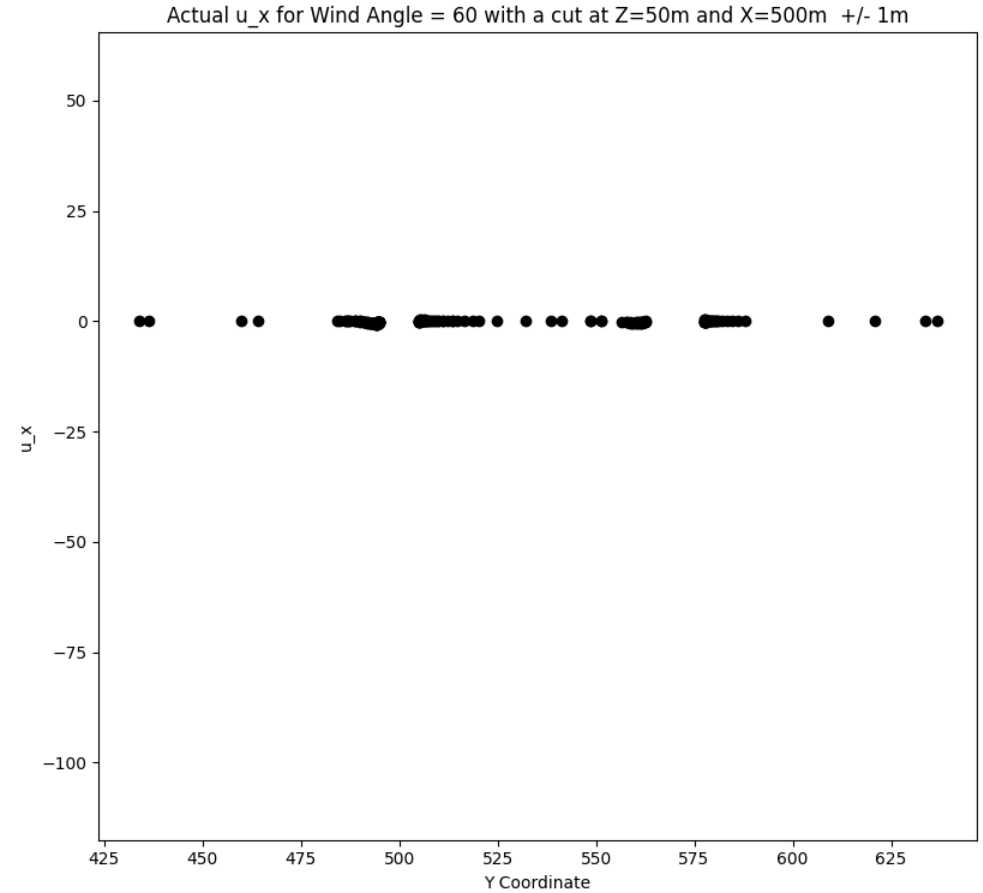


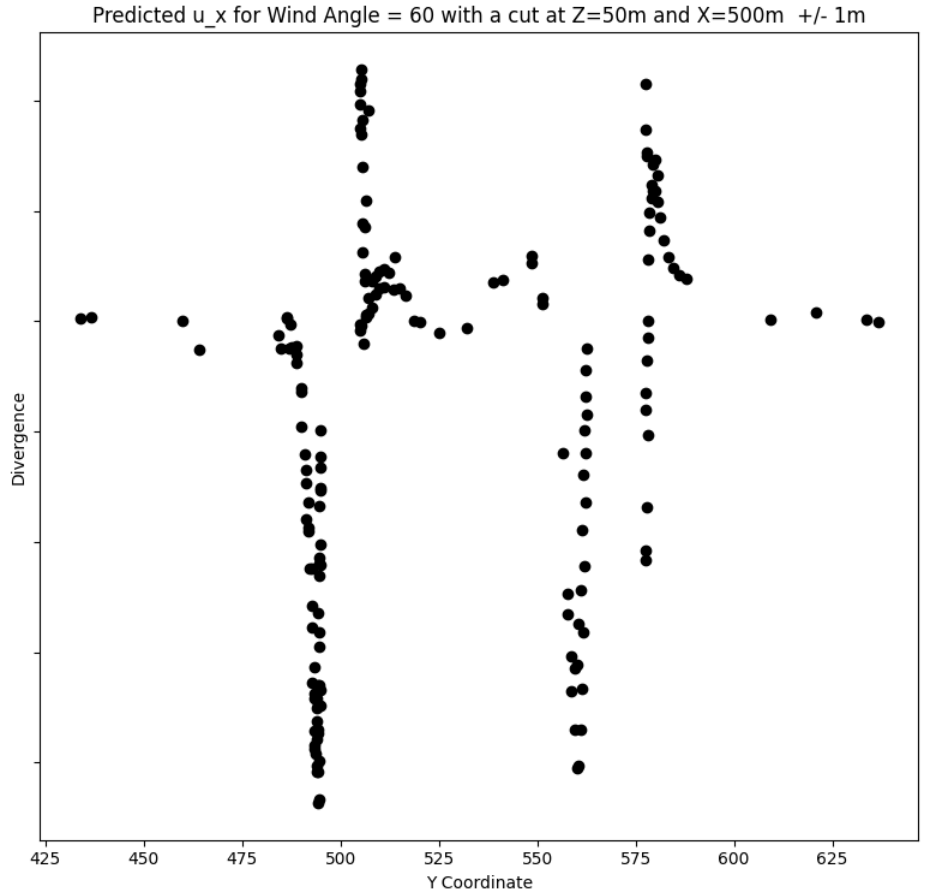
Comparison of Actual vs. Predicted values with Wind Angle = 45



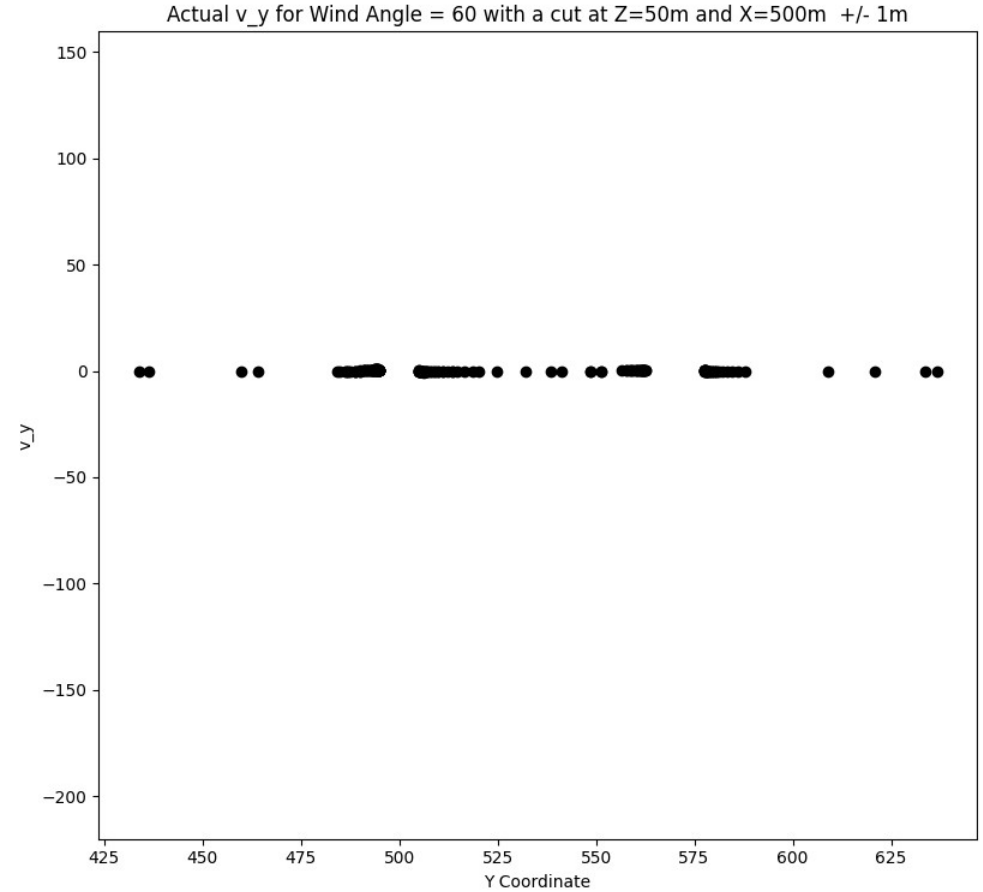


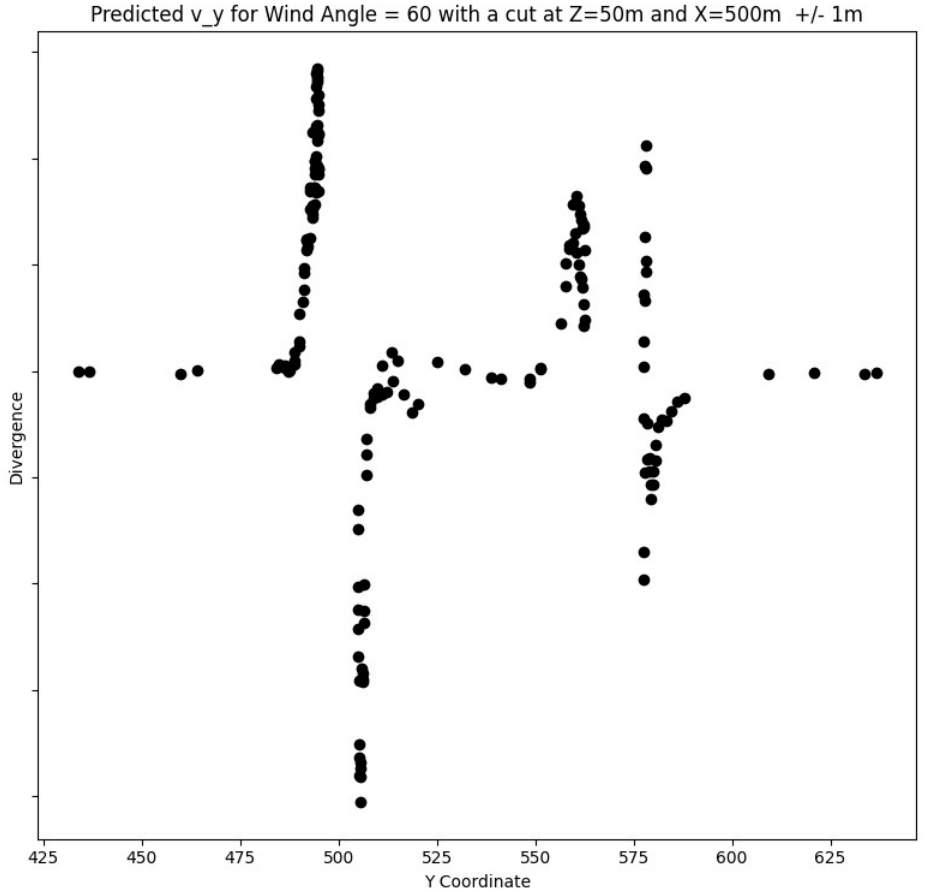
Comparison of Actual vs. Predicted values with Wind Angle = 60



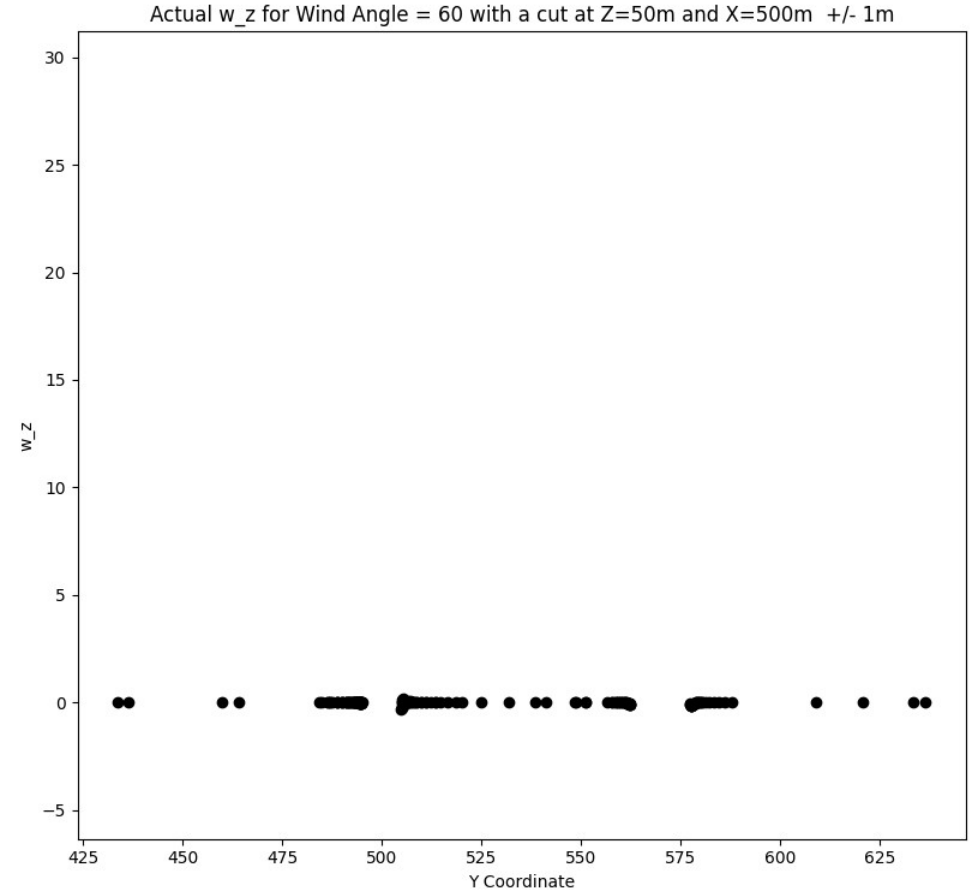


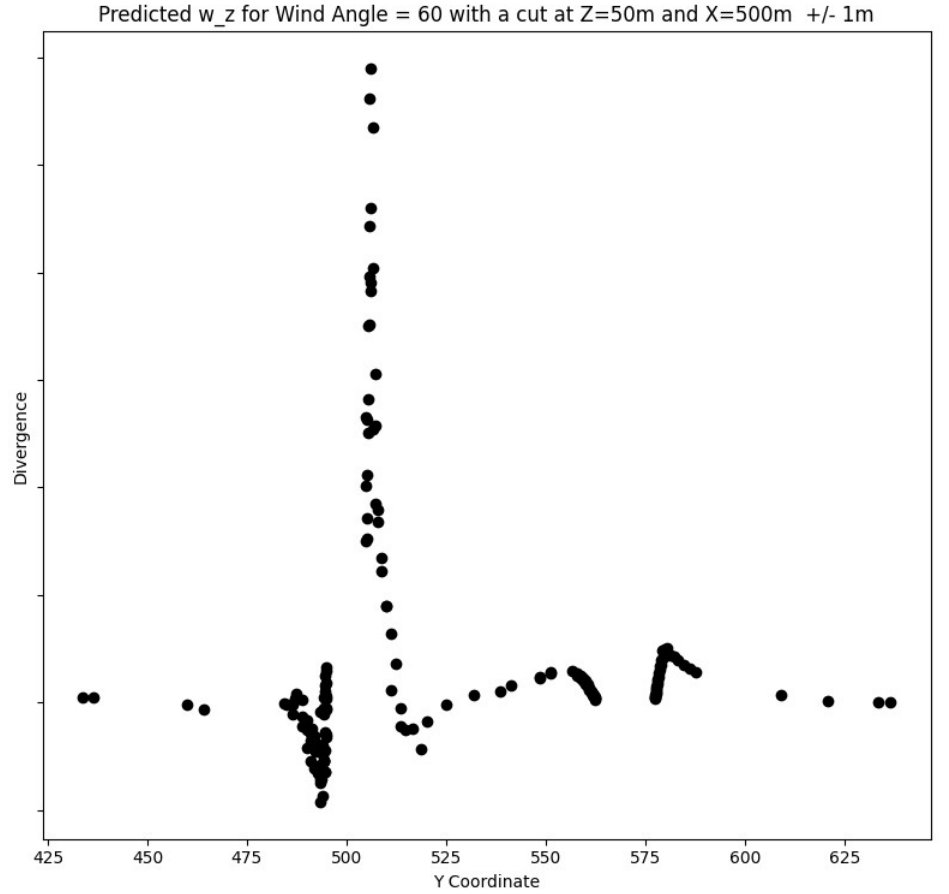
Comparison of Actual vs. Predicted values with Wind Angle = 60



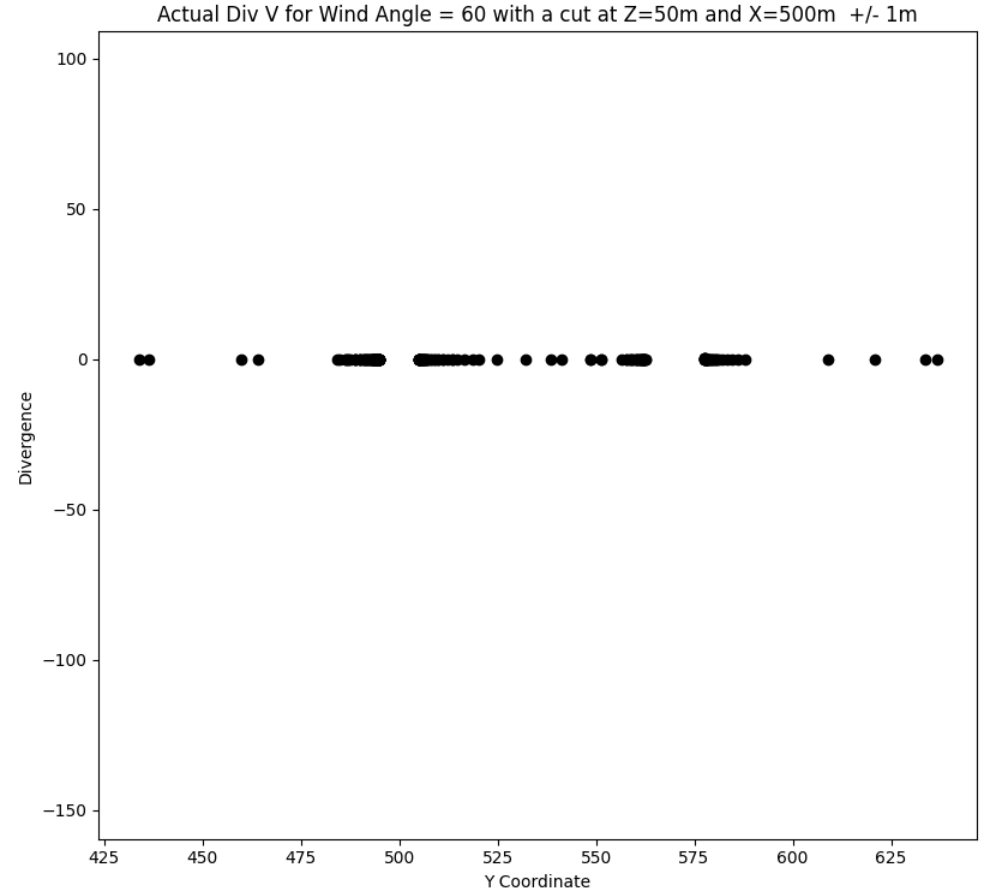


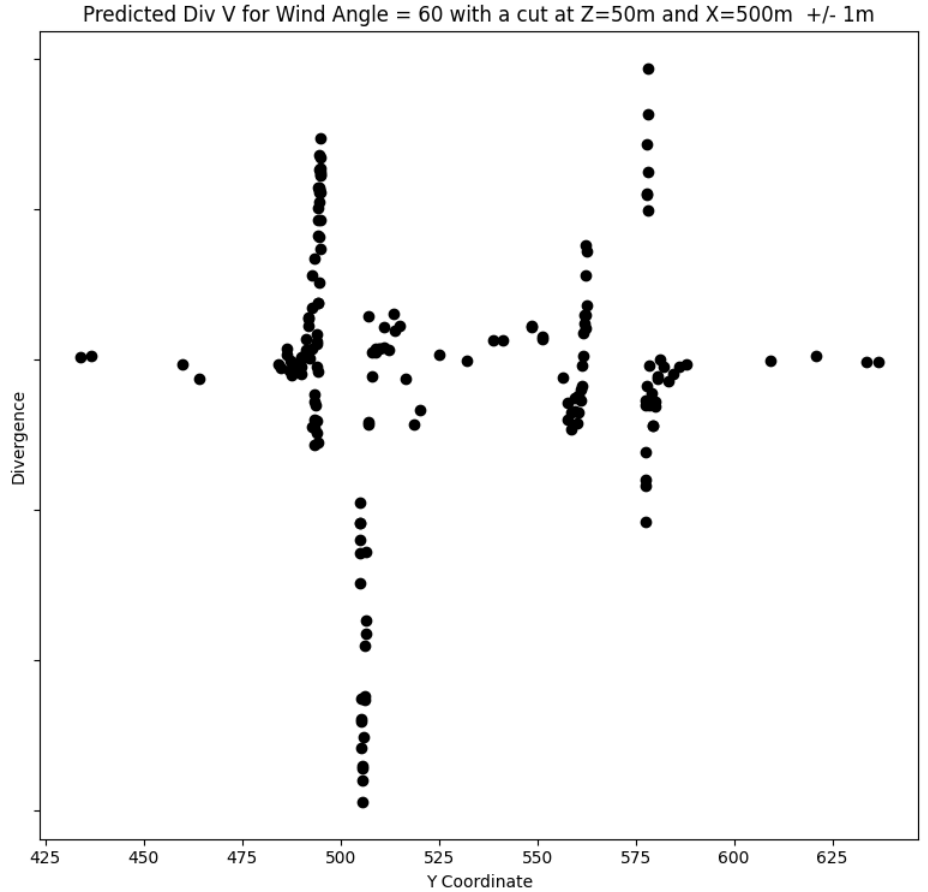
Comparison of Actual vs. Predicted values with Wind Angle = 60



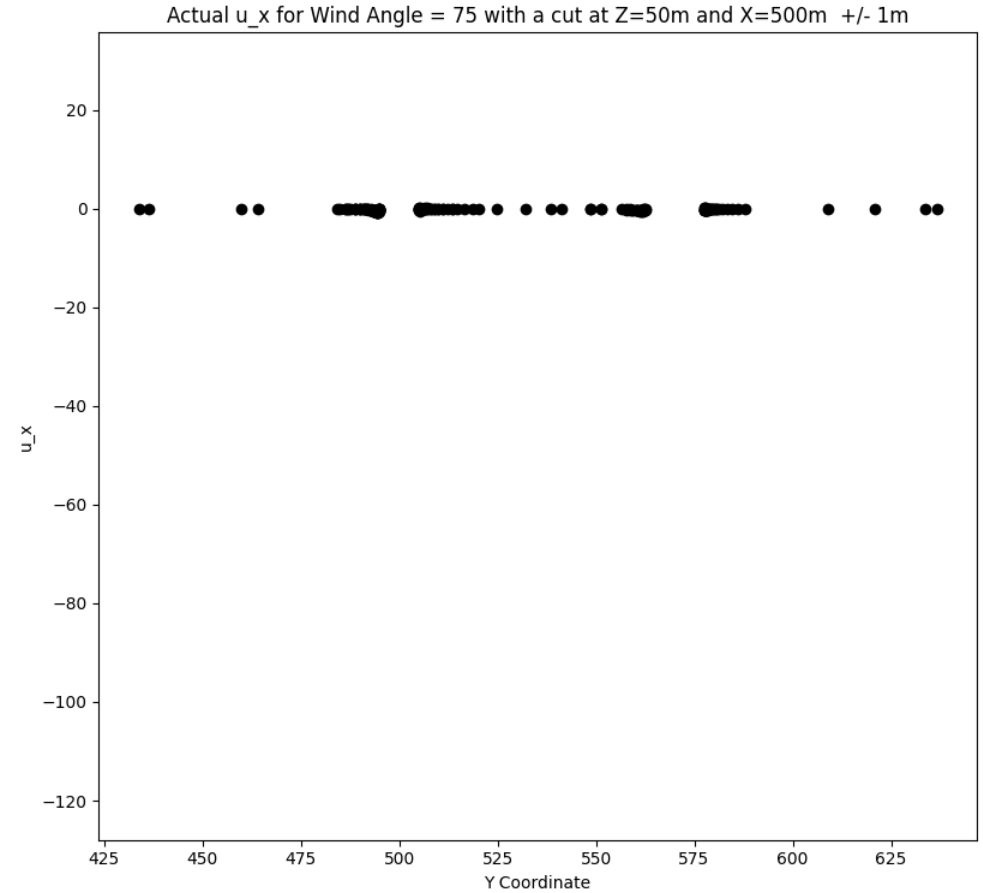


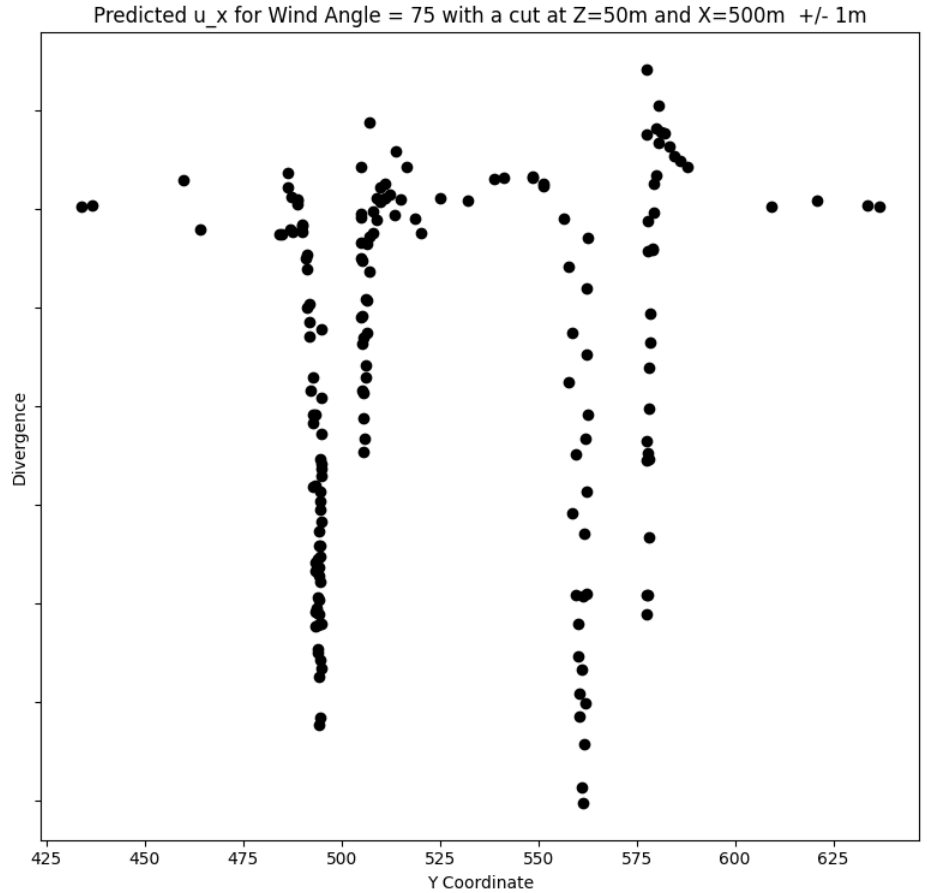
Comparison of Actual vs. Predicted values with Wind Angle = 60



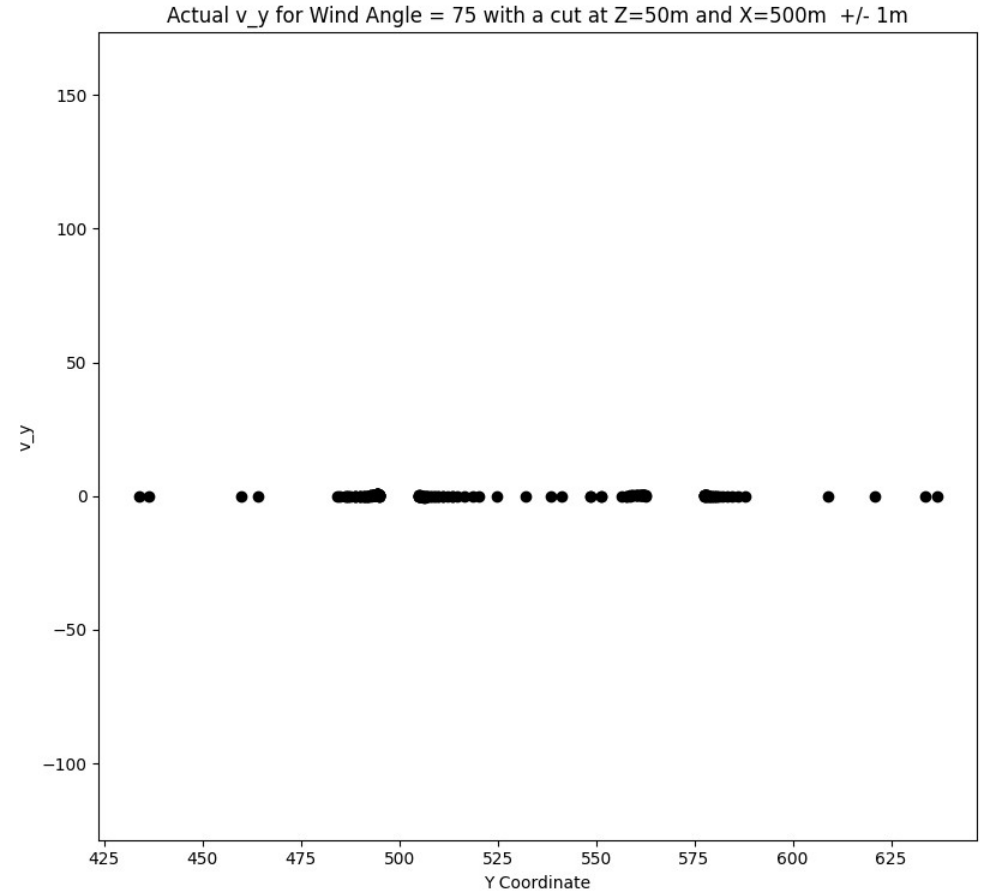


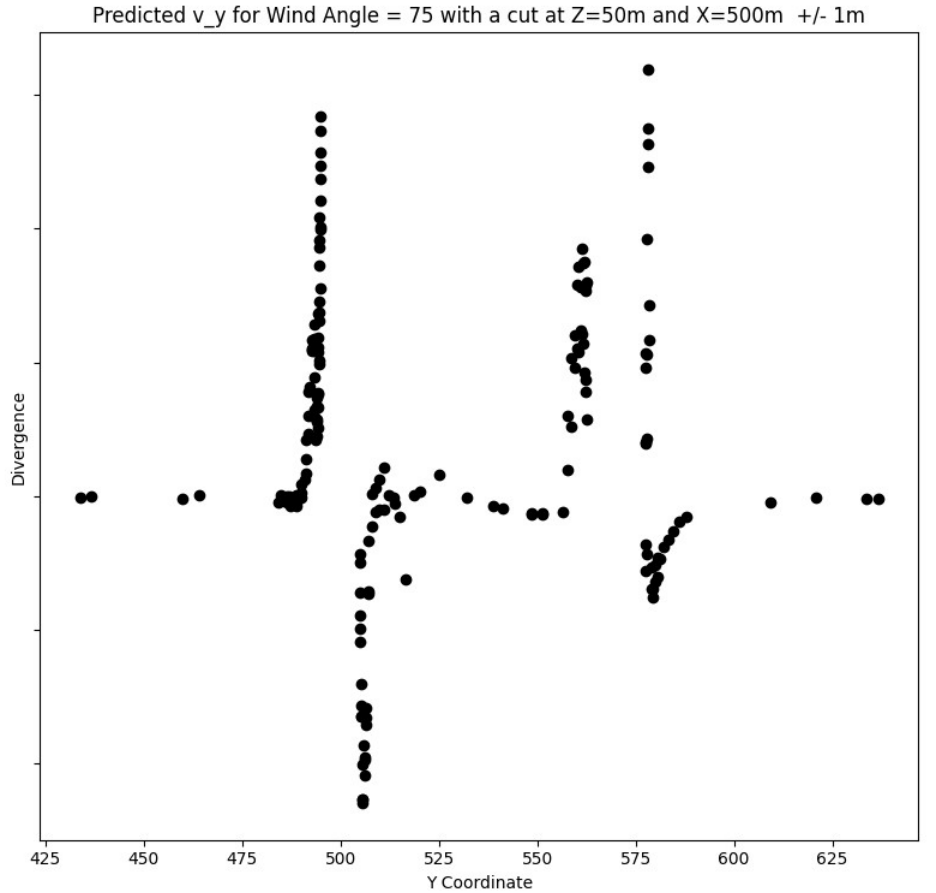
Comparison of Actual vs. Predicted values with Wind Angle = 75



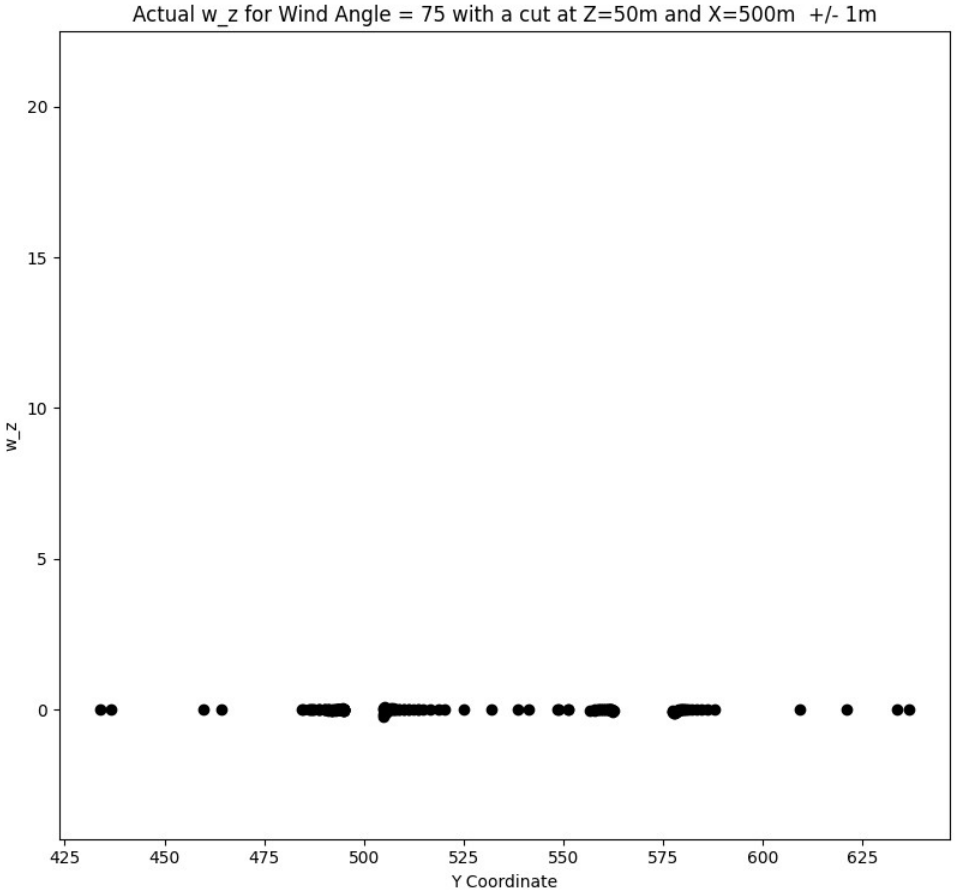


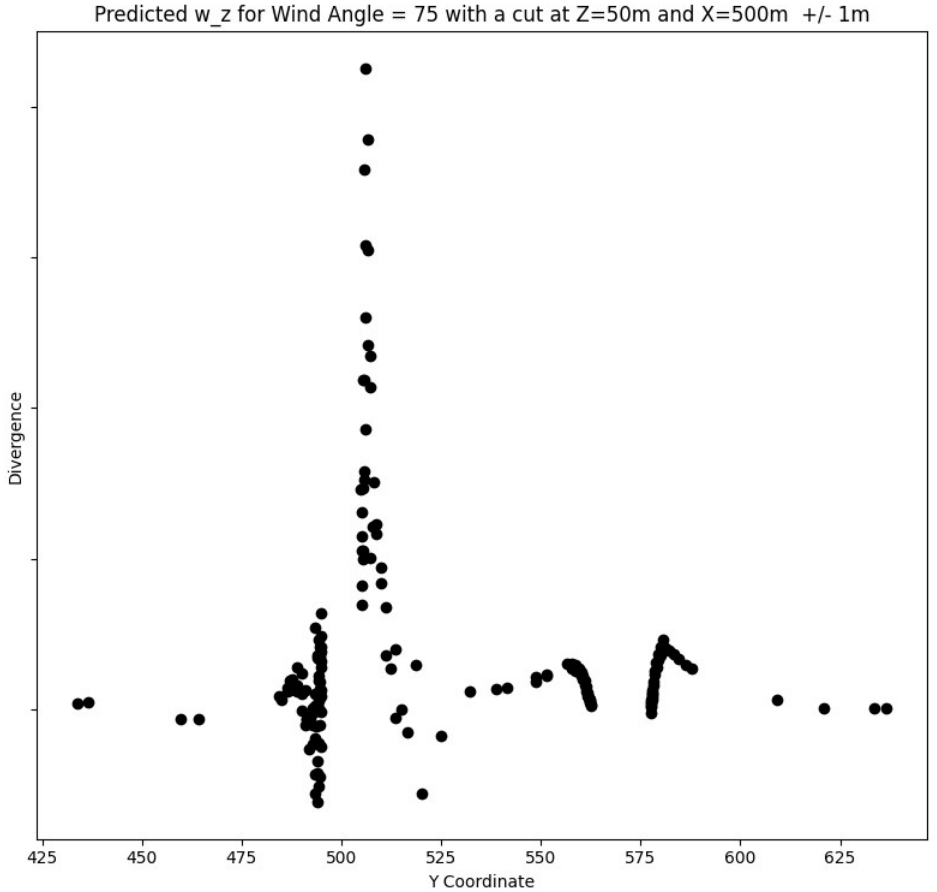
Comparison of Actual vs. Predicted values with Wind Angle = 75



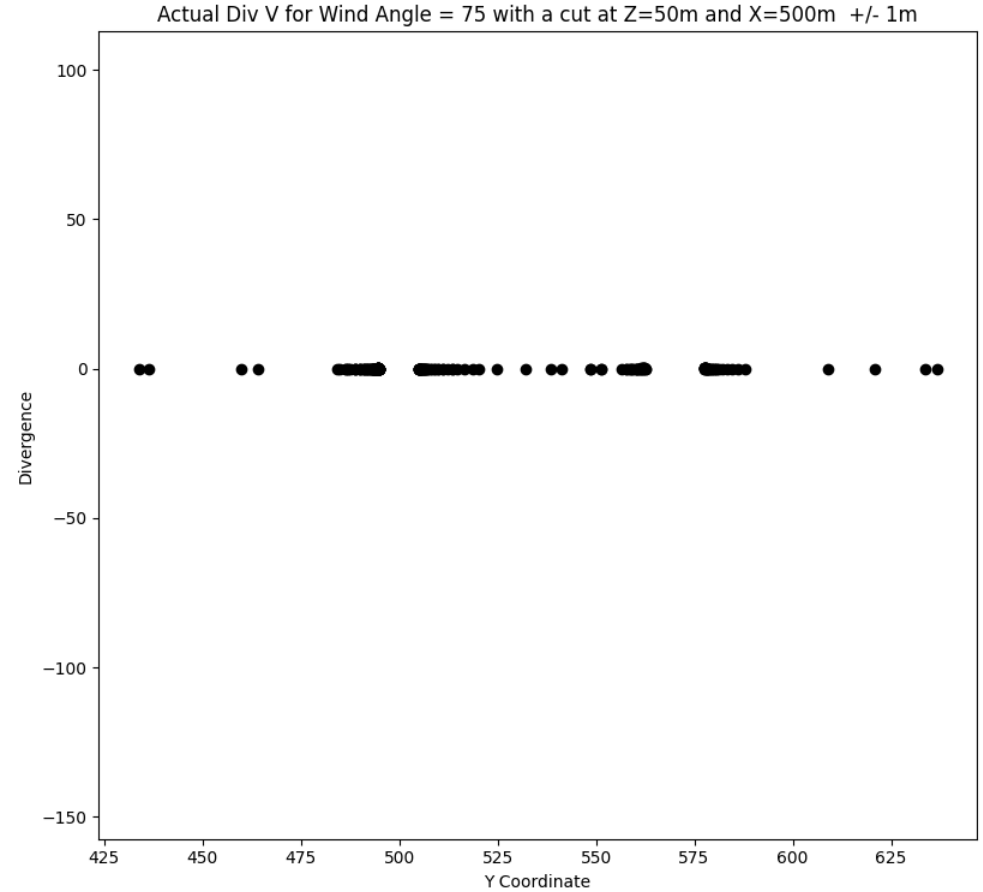


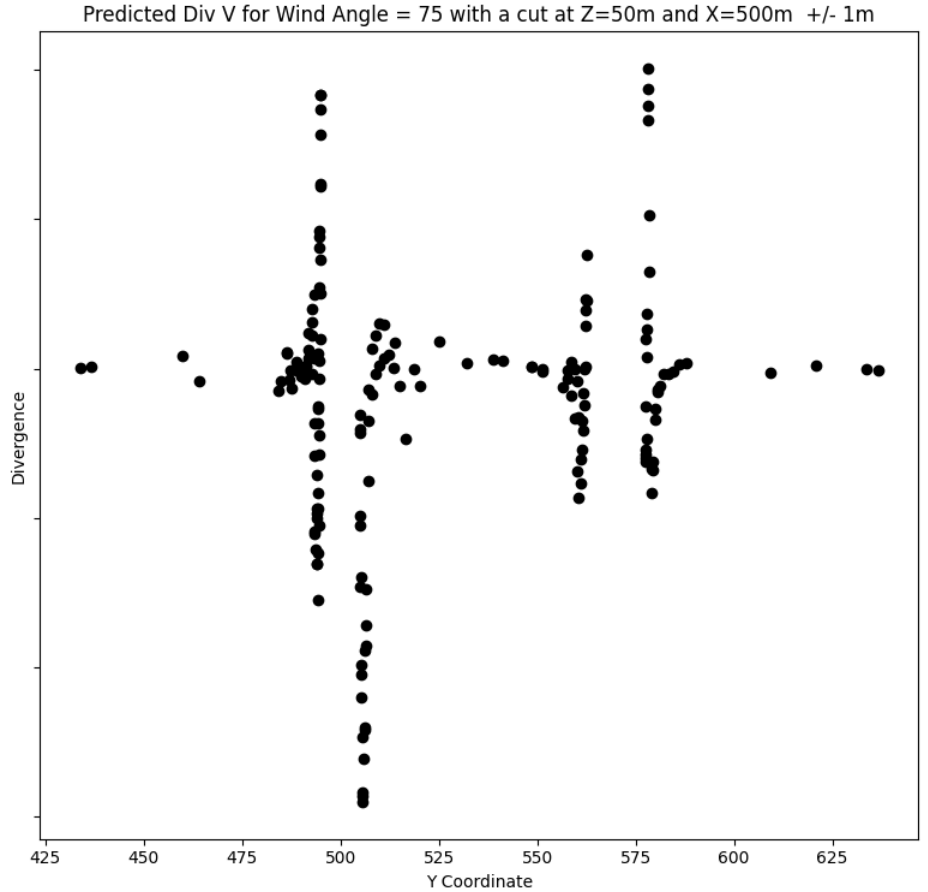
Comparison of Actual vs. Predicted values with Wind Angle = 75

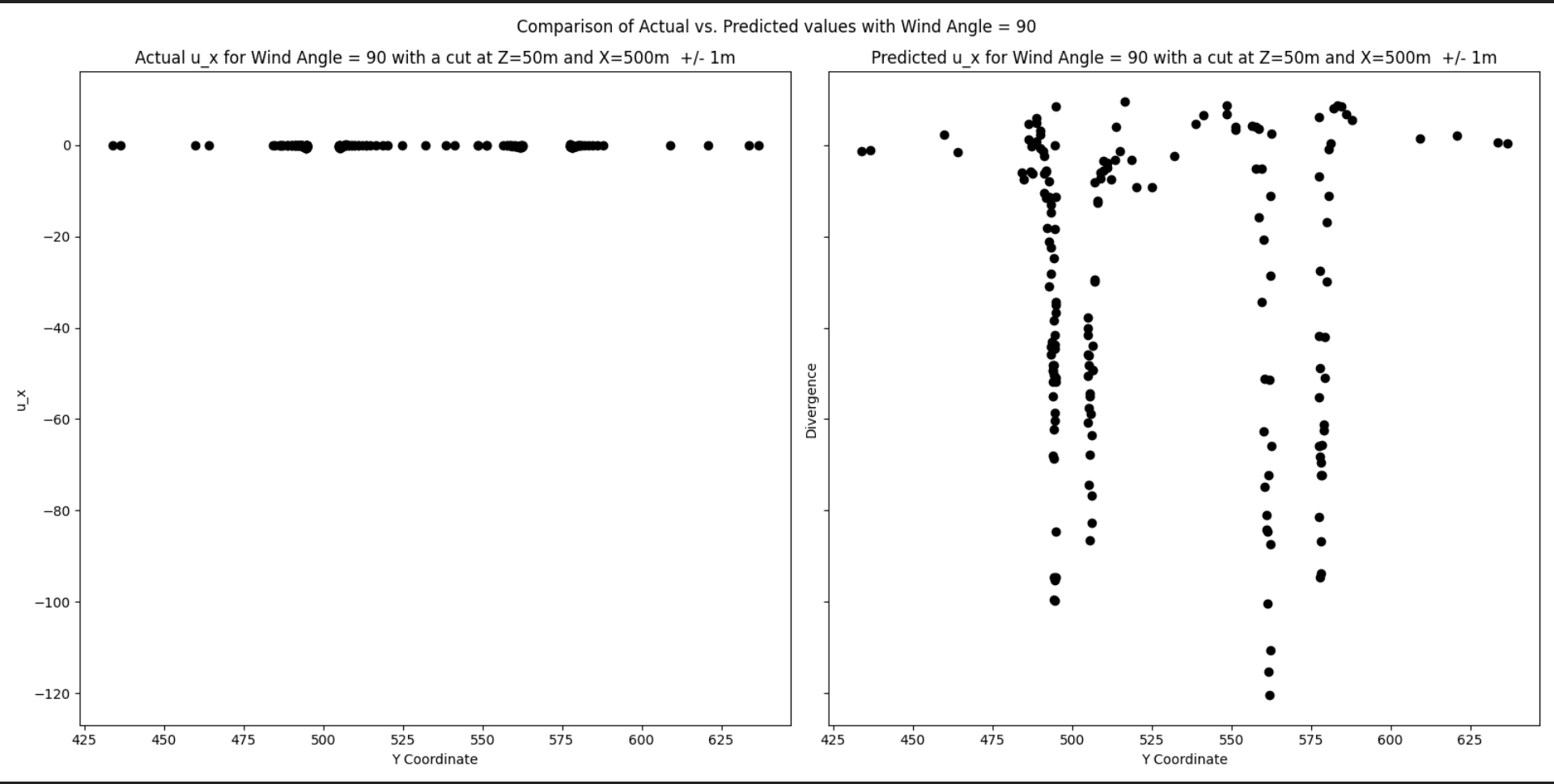




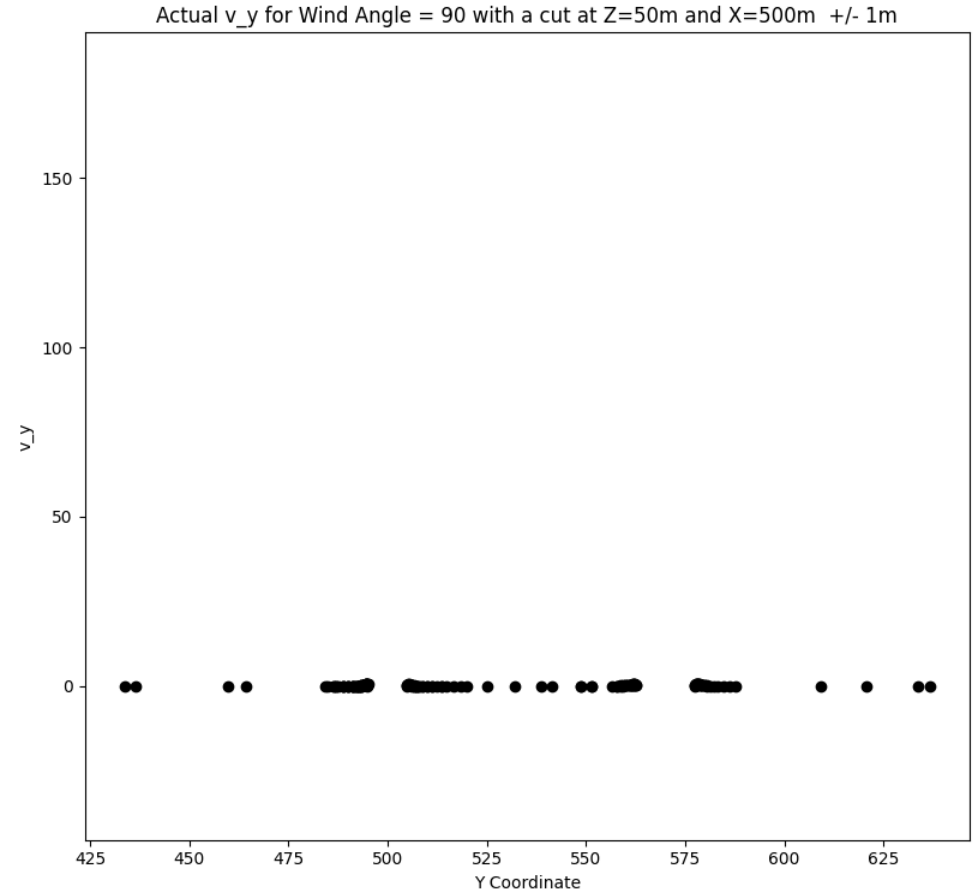
Comparison of Actual vs. Predicted values with Wind Angle = 75

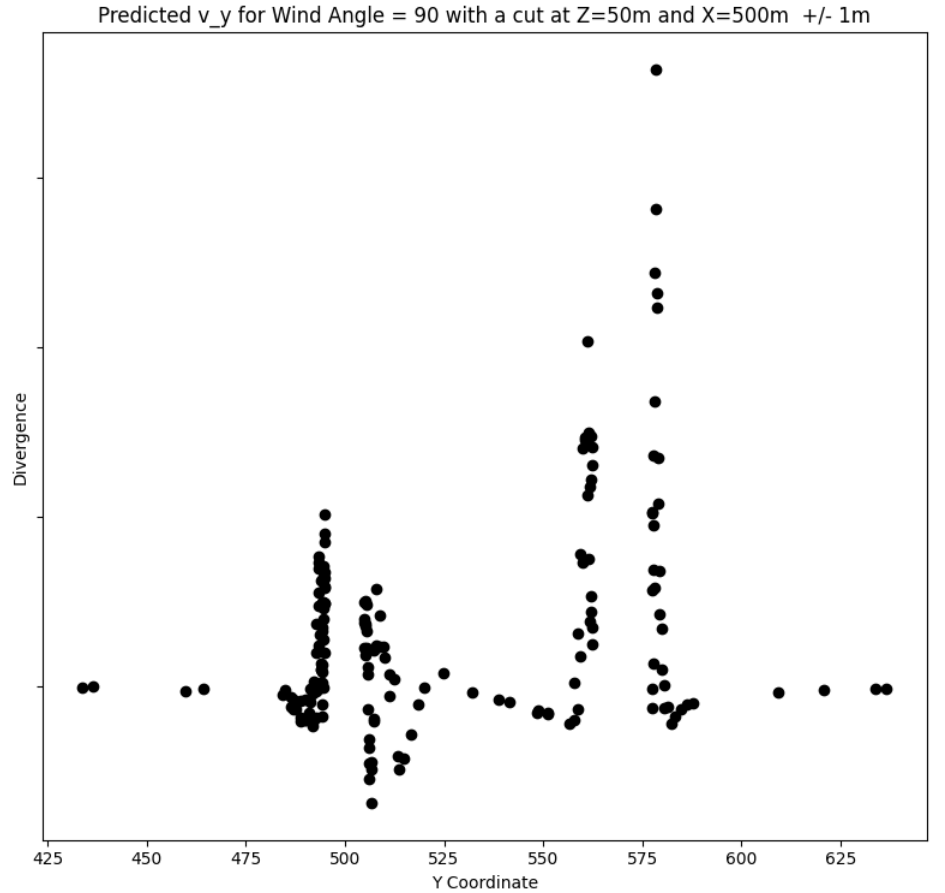




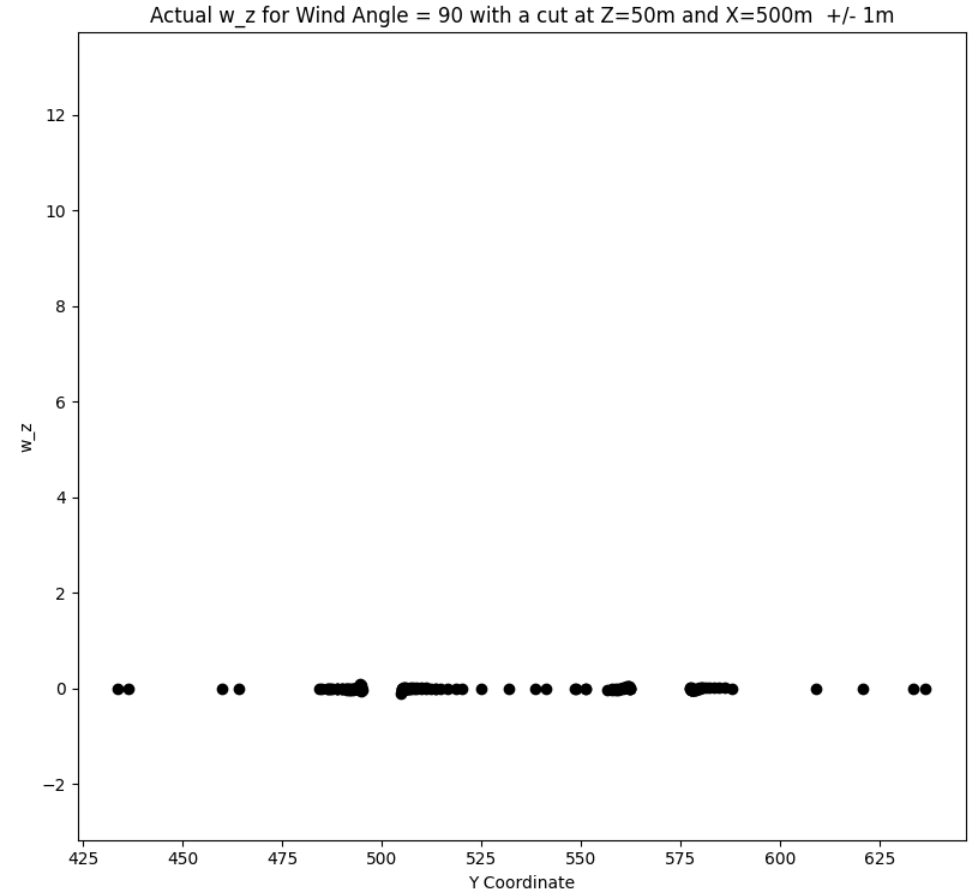

Comparison of Actual vs. Predicted values with Wind Angle = 90
Actual u_x for Wind Angle = 90 with a cut at Z=50m and X=500m +/- 1m
Predicted u_x for Wind Angle = 90 with a cut at Z=50m and X=500m +/- 1m
u_x
Divergence
0
−20
−40
−60
−80
−100
−120
425
450
475
500
525
550
575
600
625
Y Coordinate
Y Coordinate

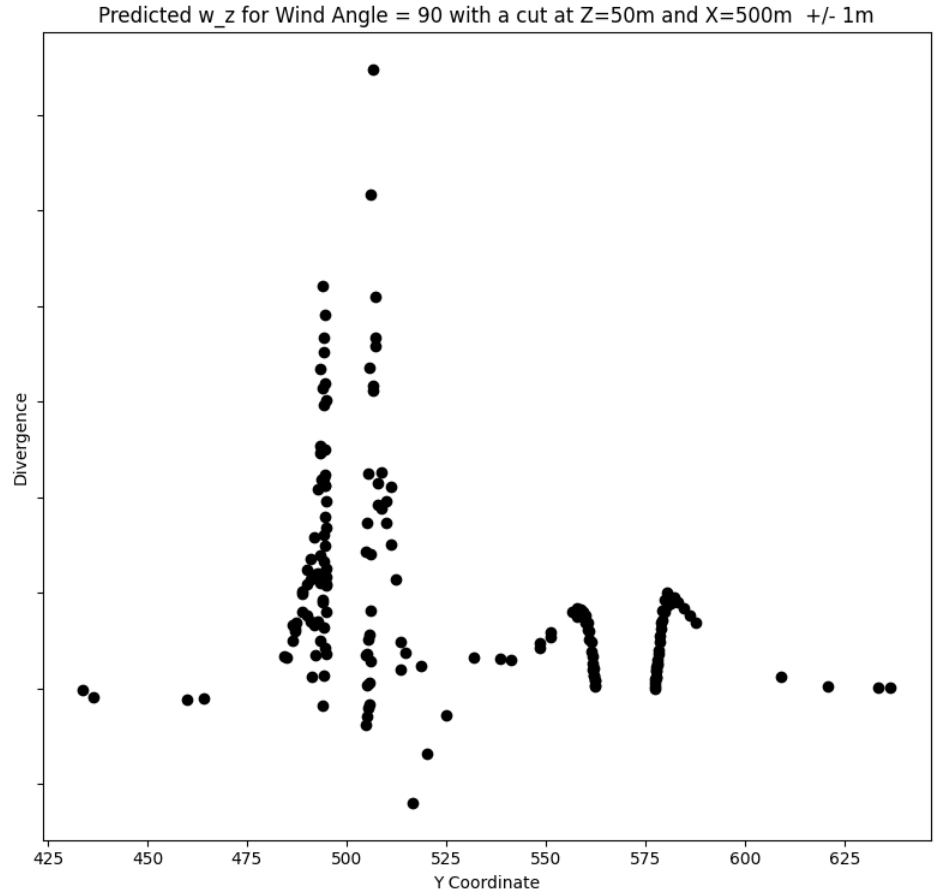
Comparison of Actual vs. Predicted values with Wind Angle = 90



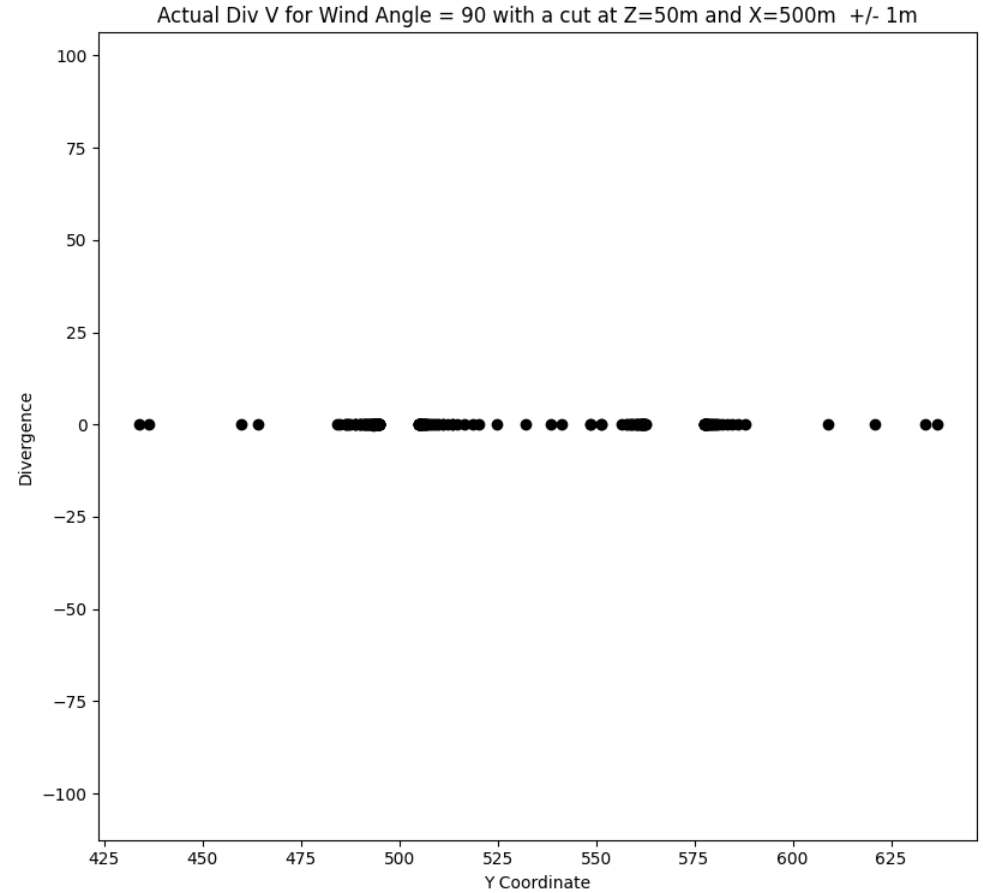


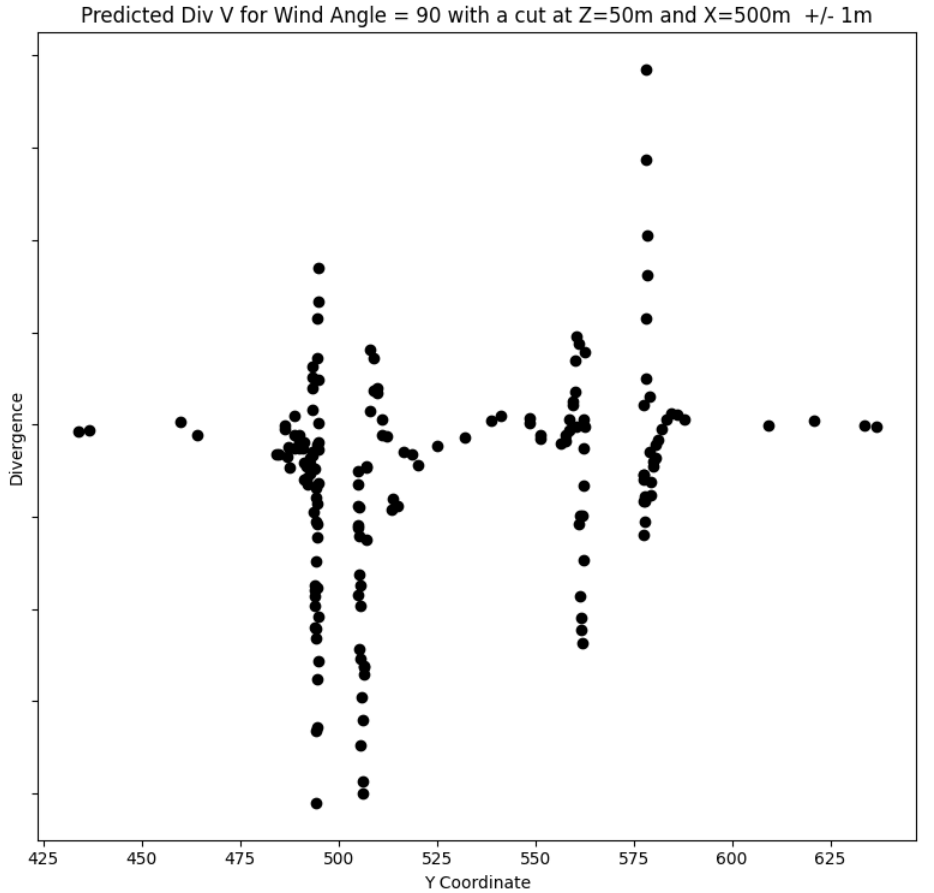
Comparison of Actual vs. Predicted values with Wind Angle = 90



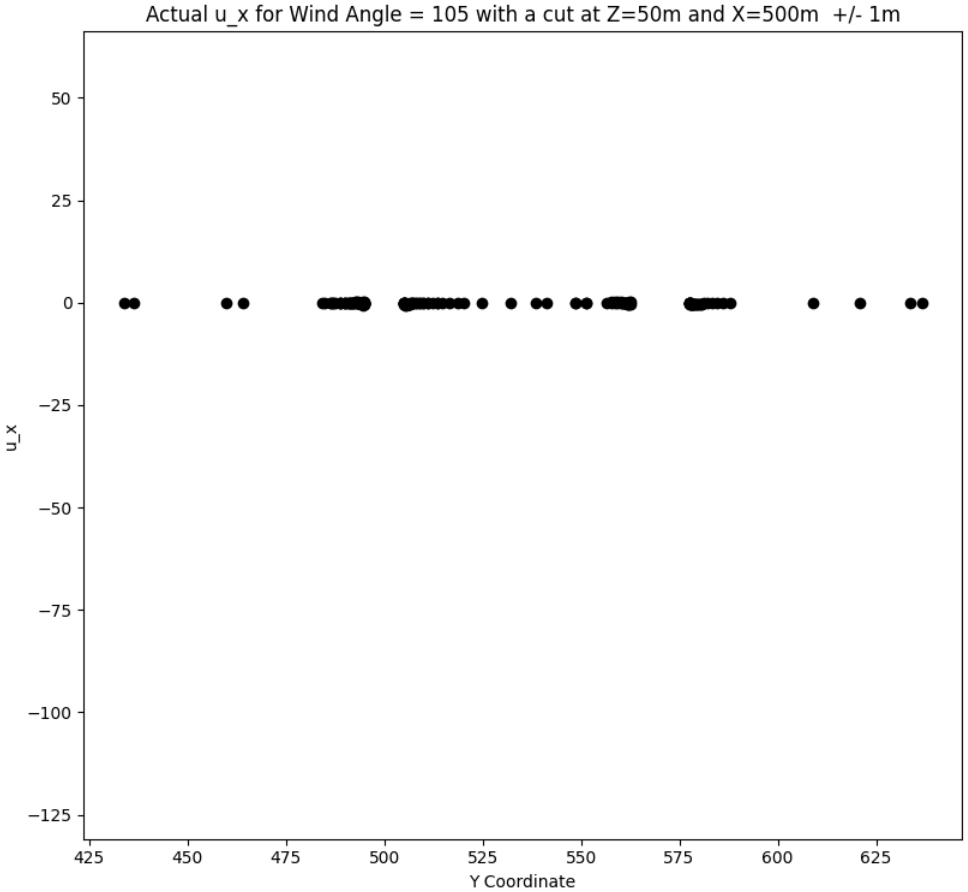


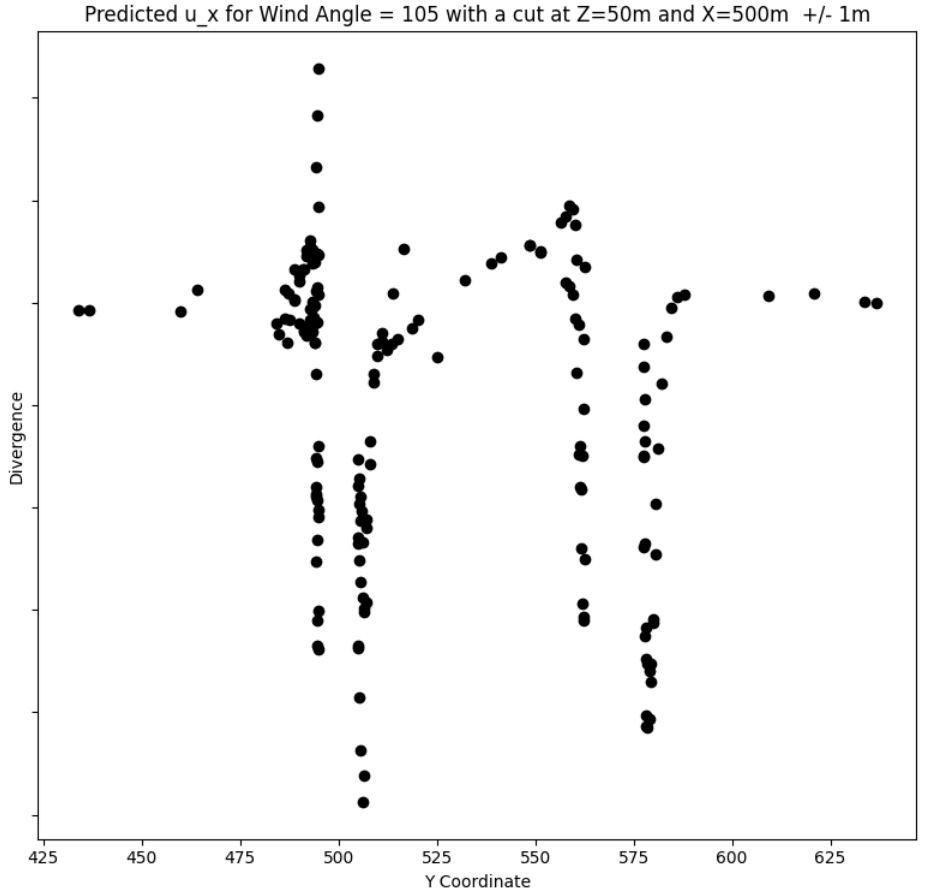
Comparison of Actual vs. Predicted values with Wind Angle = 90



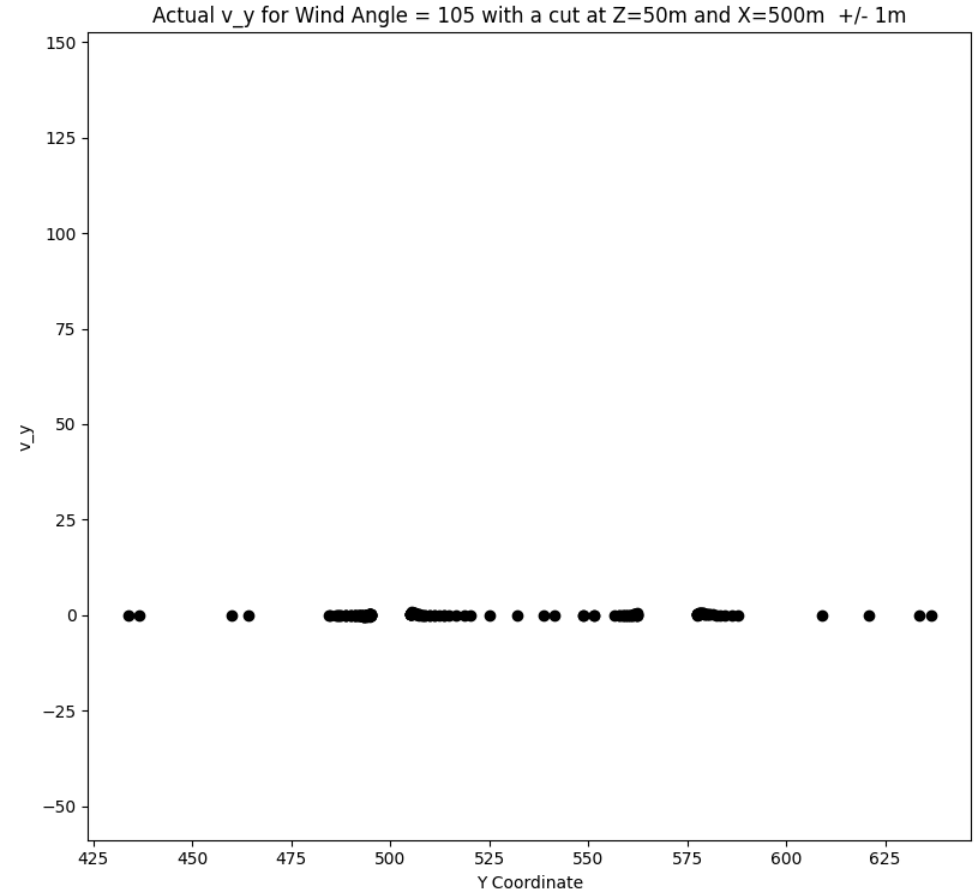


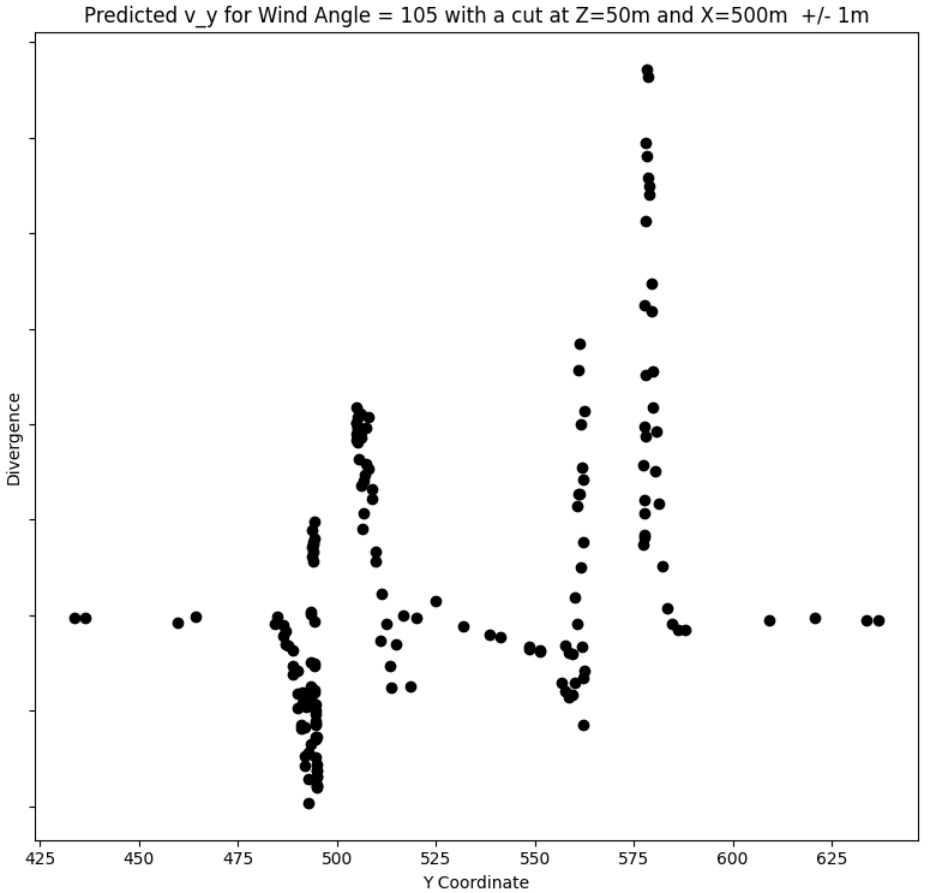
Comparison of Actual vs. Predicted values with Wind Angle = 105



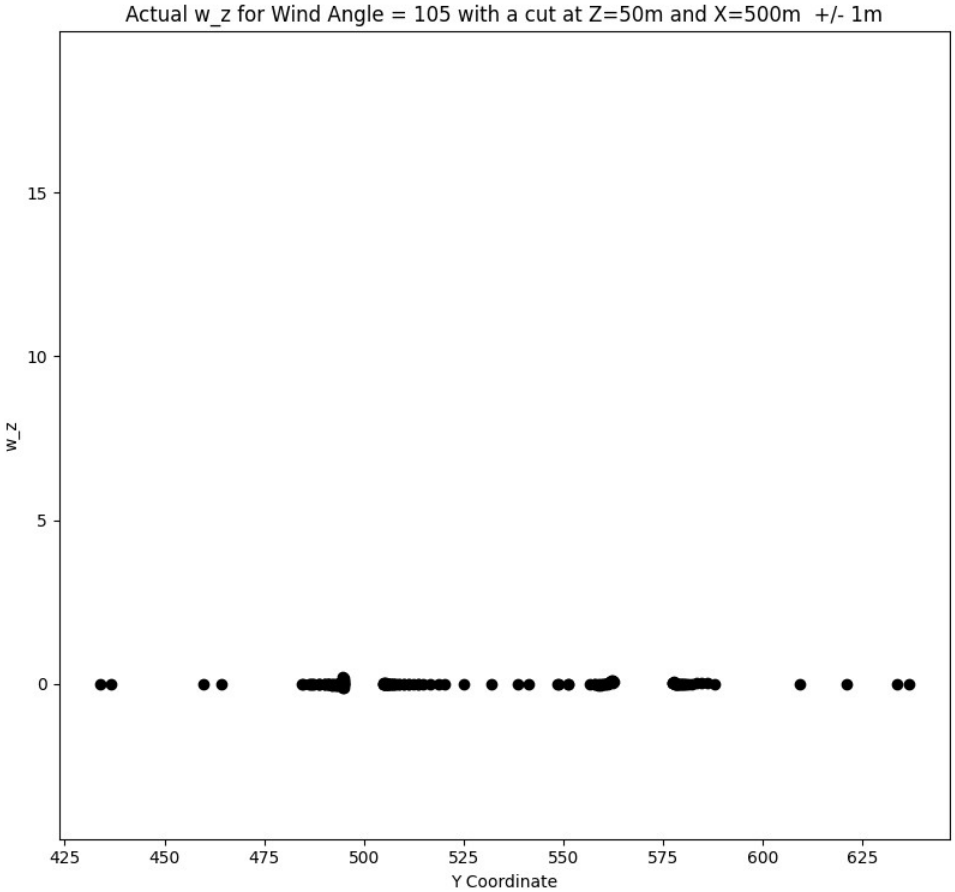


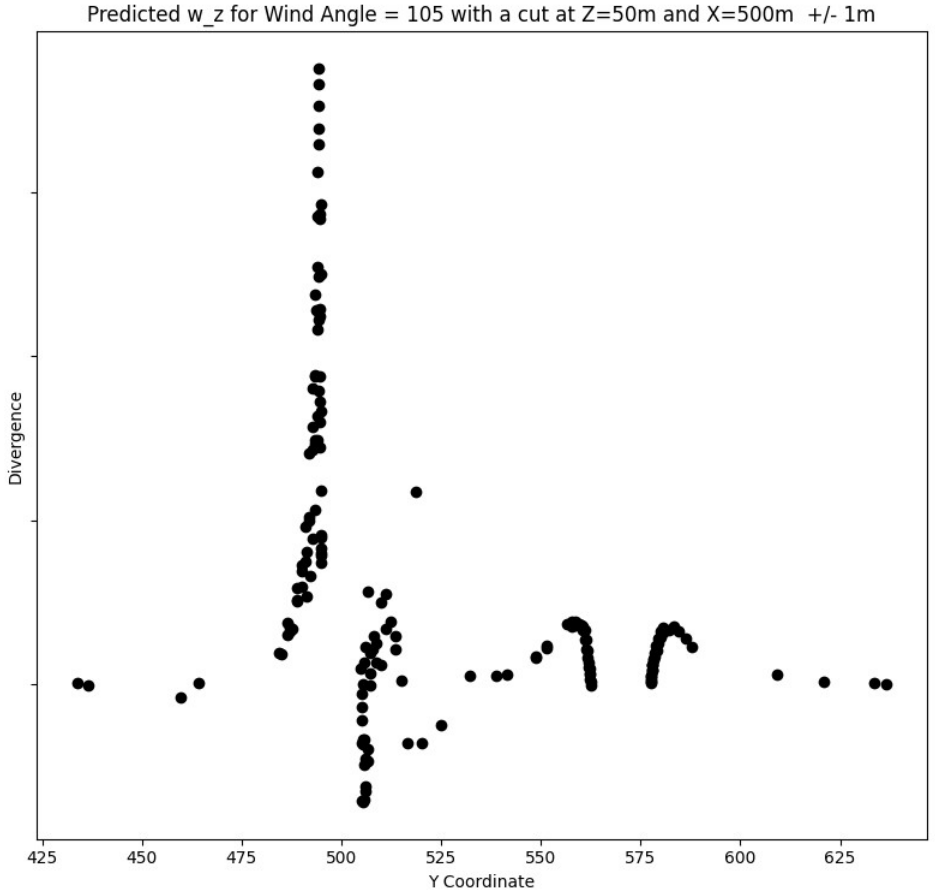
Comparison of Actual vs. Predicted values with Wind Angle = 105



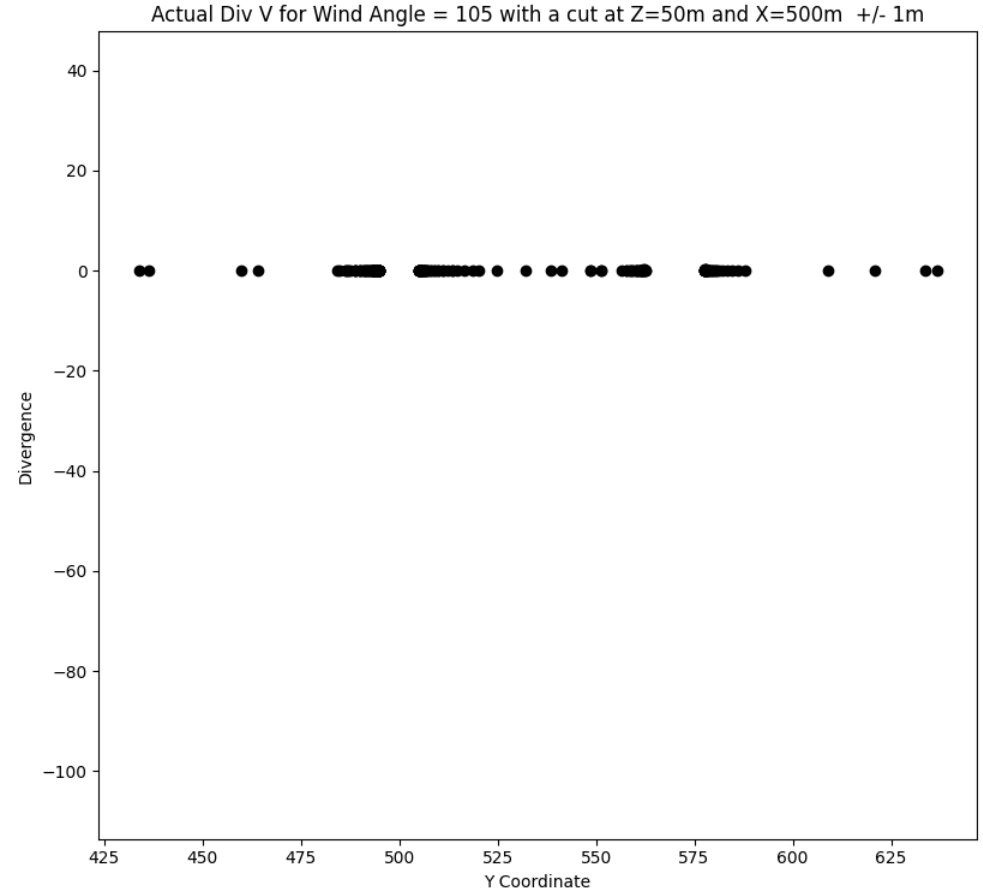


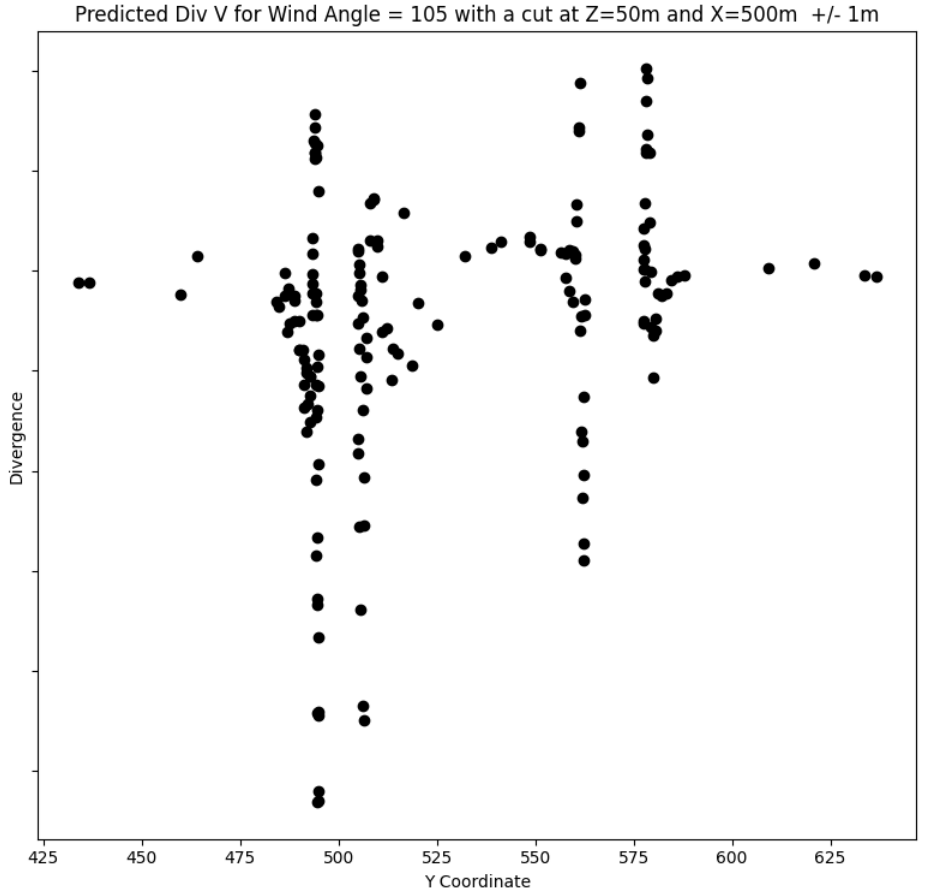
Comparison of Actual vs. Predicted values with Wind Angle = 105



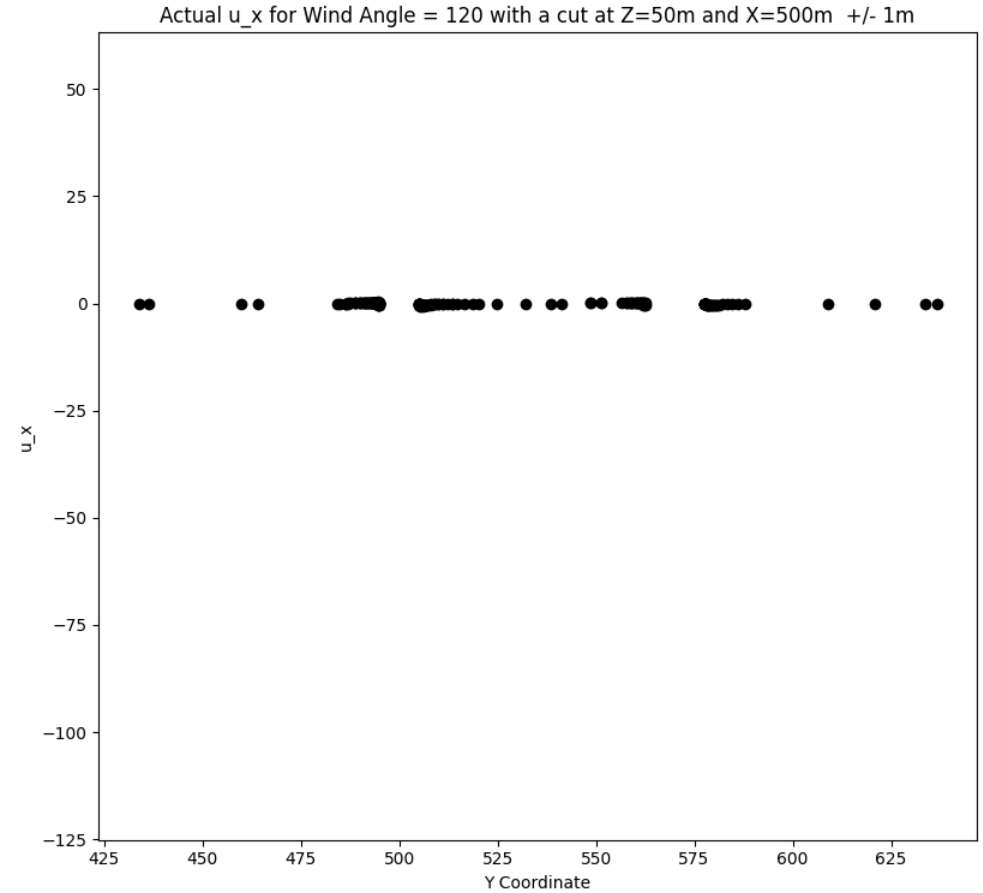


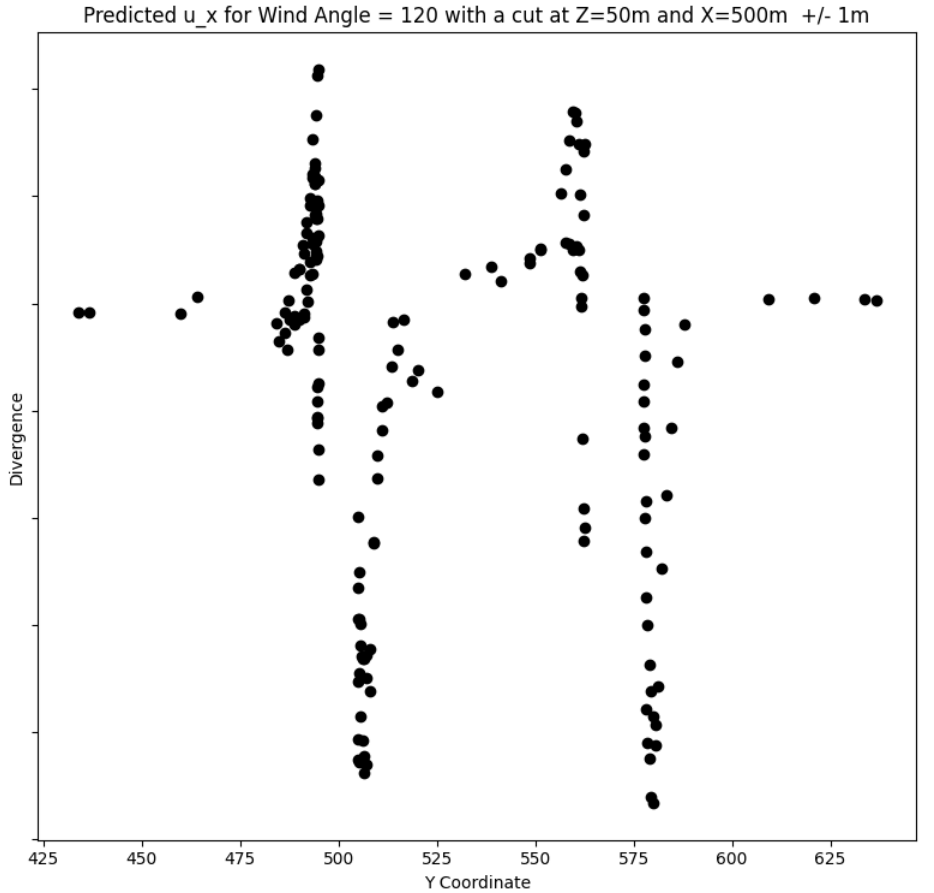
Comparison of Actual vs. Predicted values with Wind Angle = 105



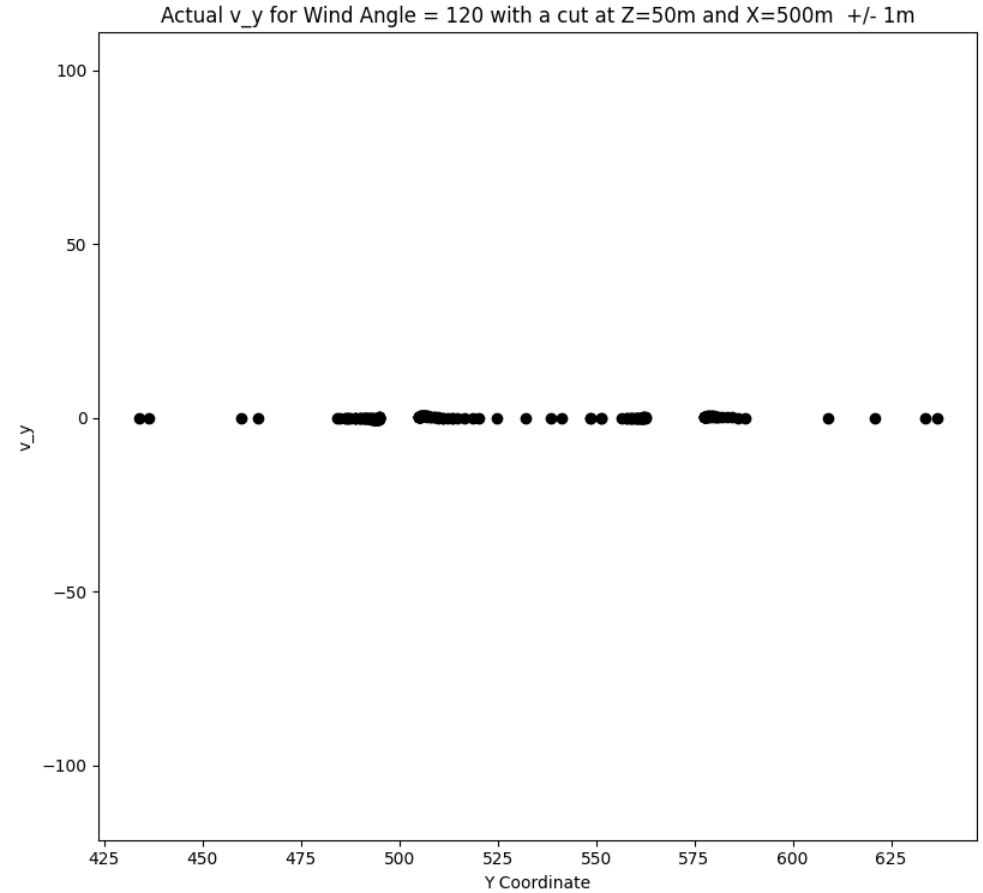


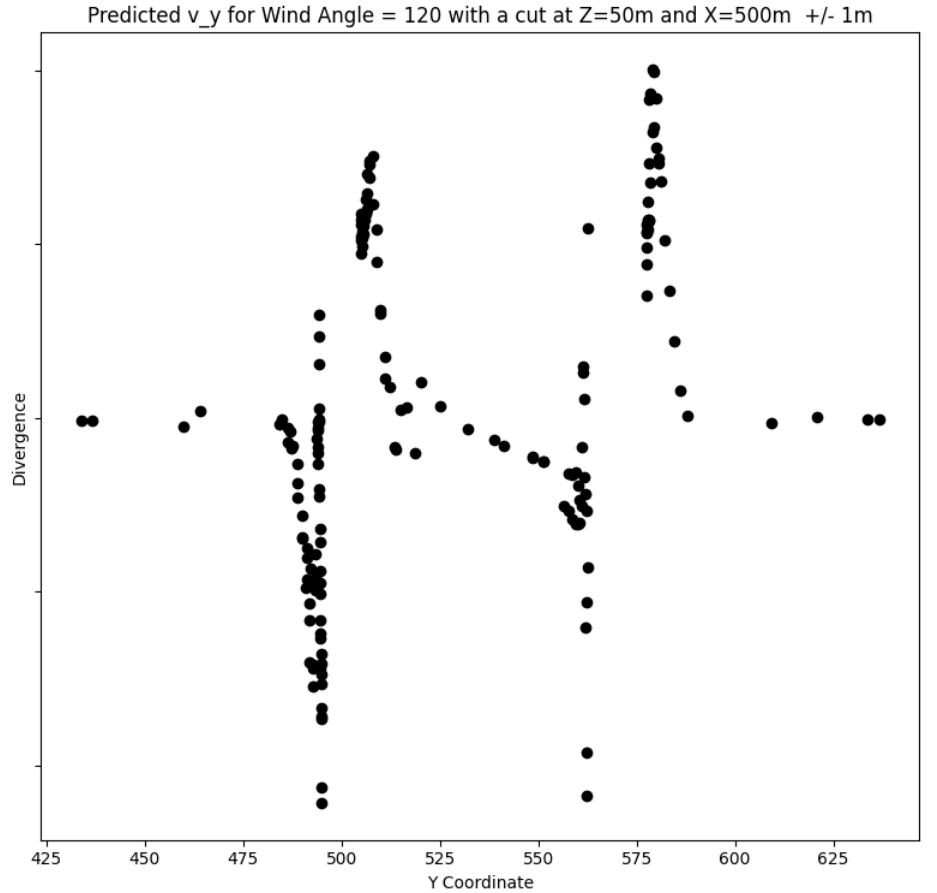
Comparison of Actual vs. Predicted values with Wind Angle = 120



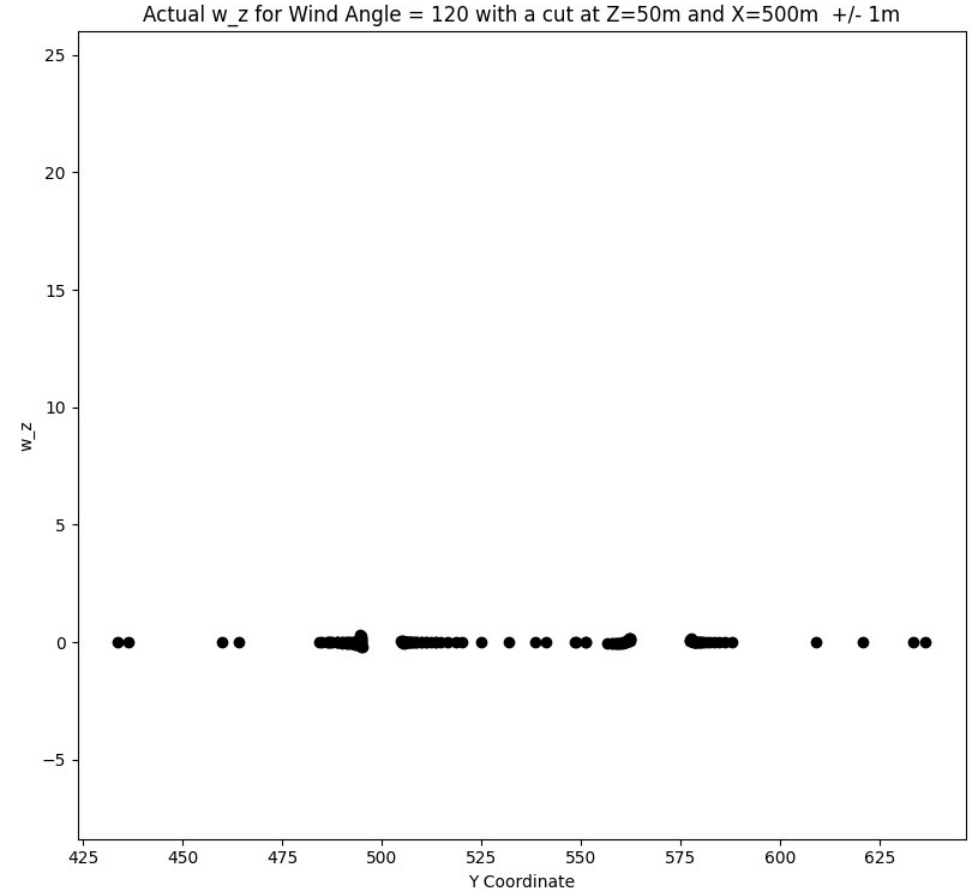


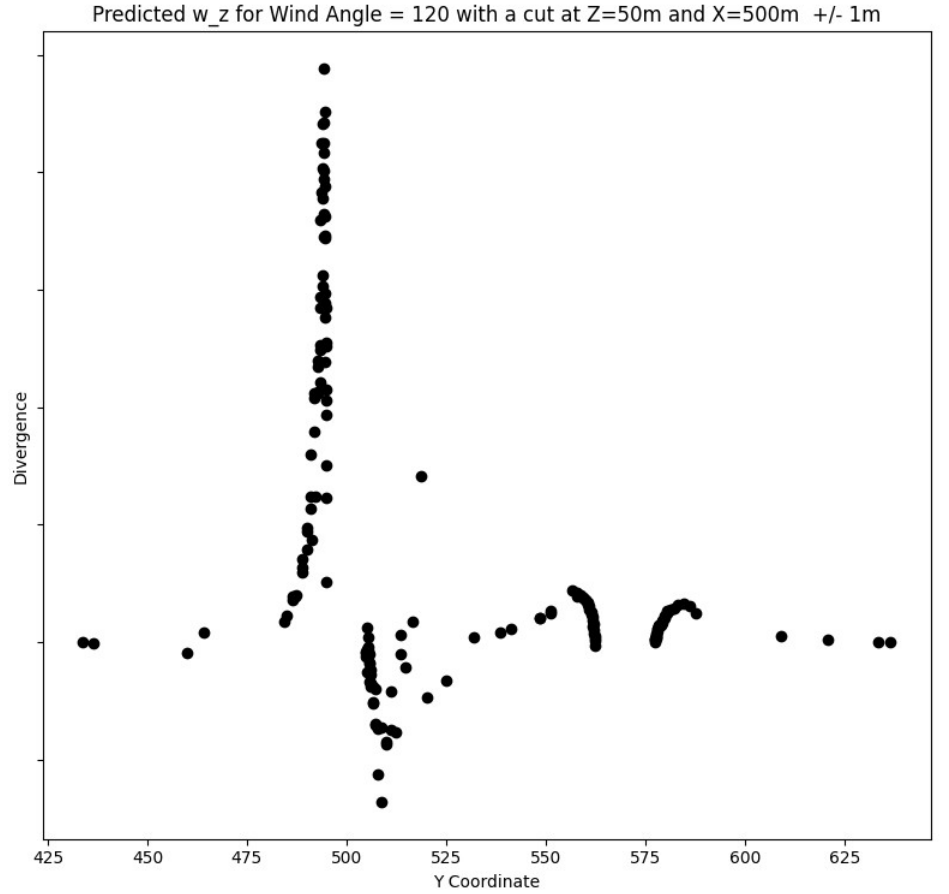
Comparison of Actual vs. Predicted values with Wind Angle = 120



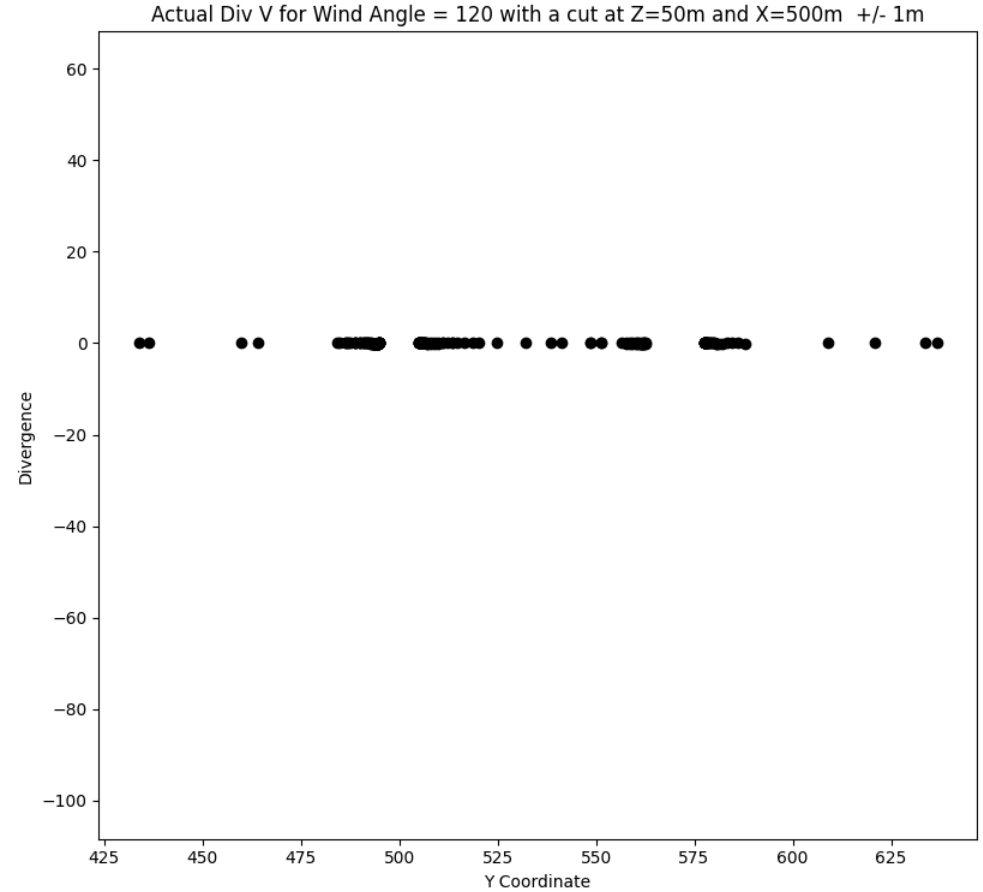


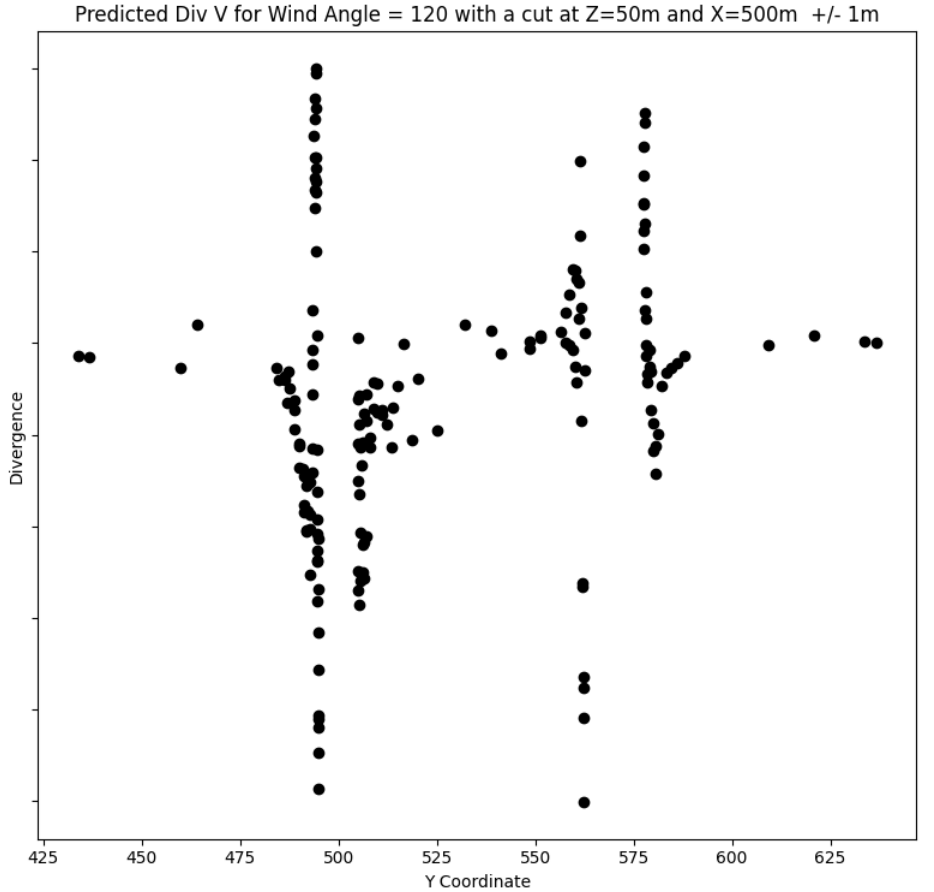
Comparison of Actual vs. Predicted values with Wind Angle = 120



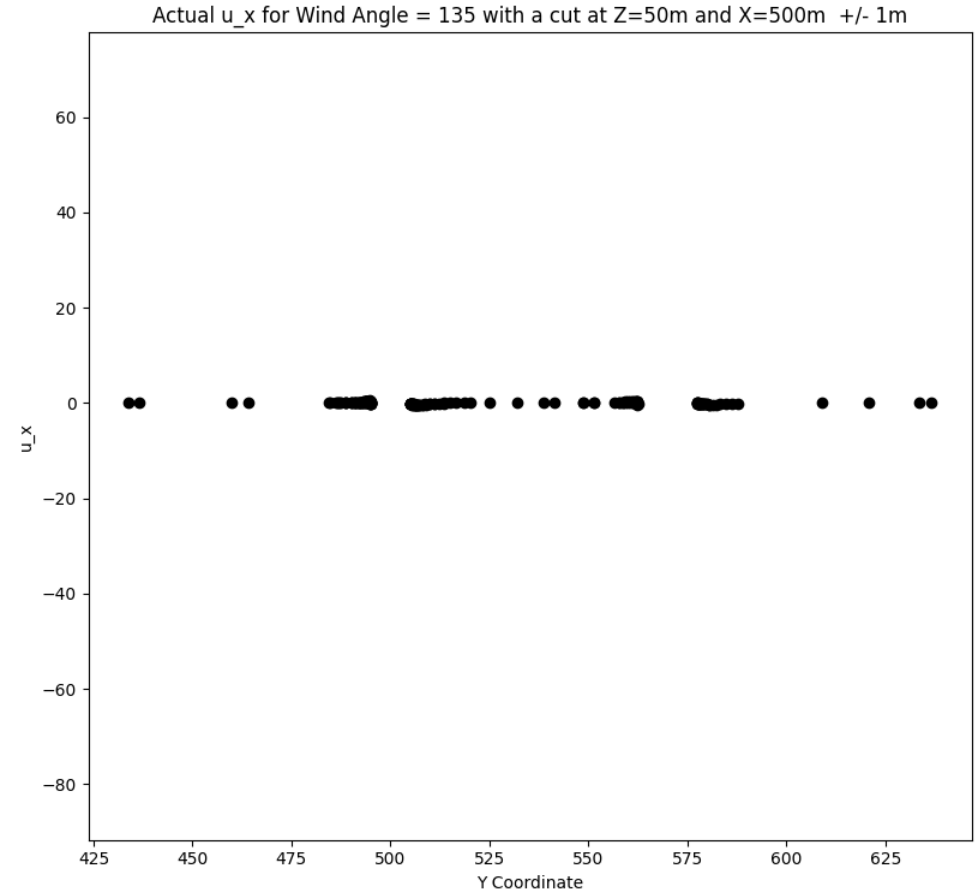


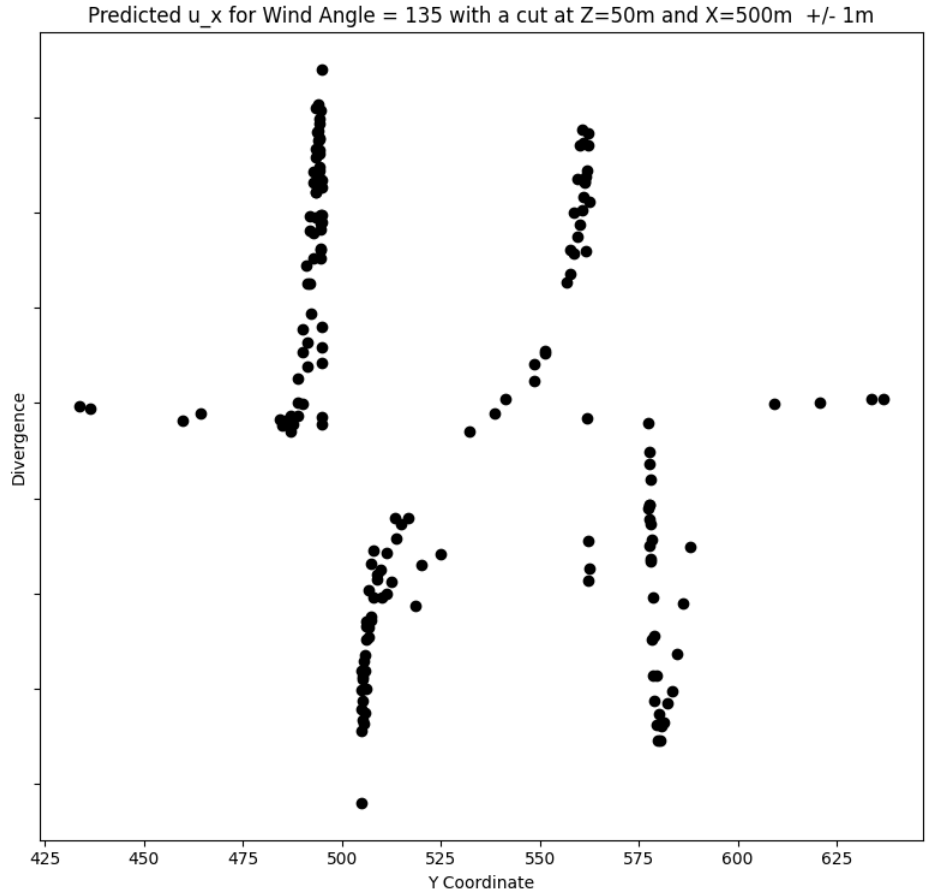
Comparison of Actual vs. Predicted values with Wind Angle = 120



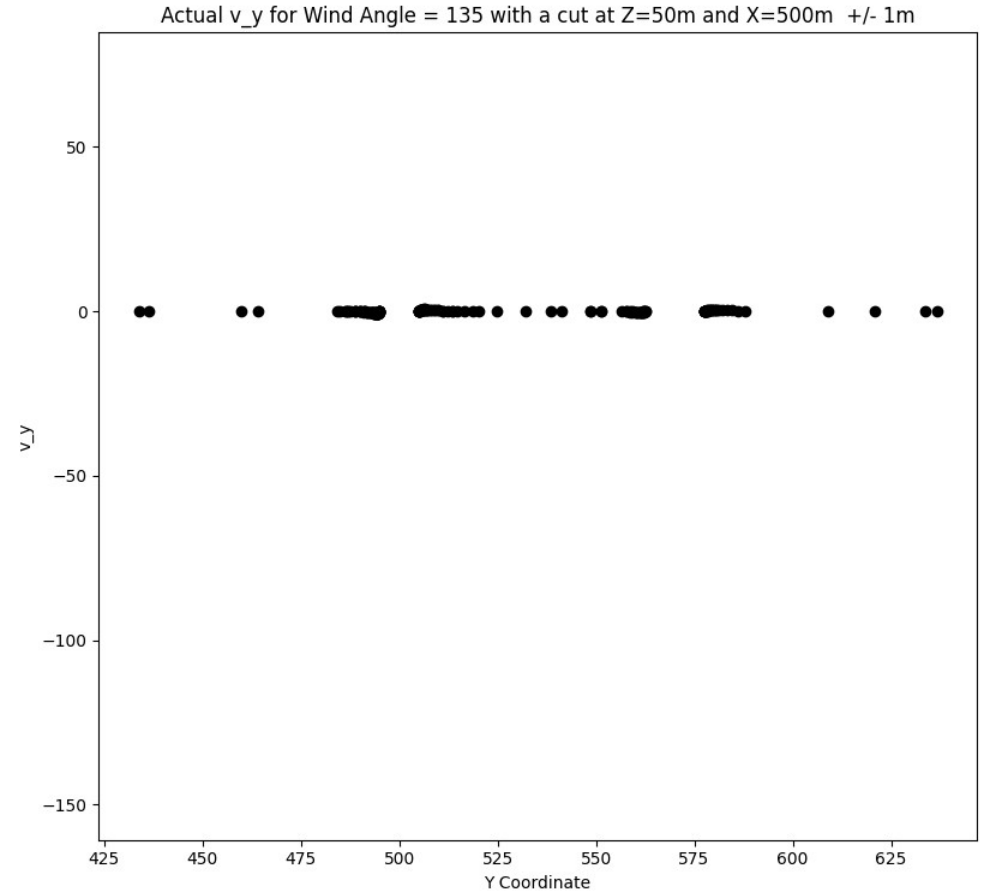


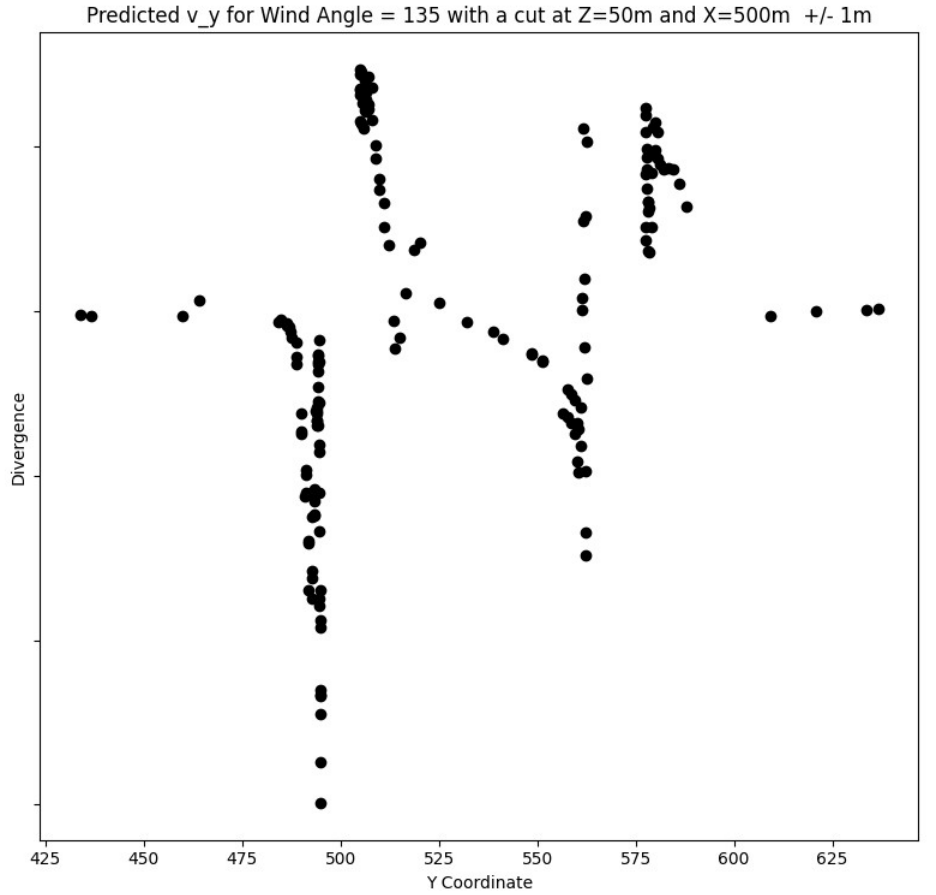
Comparison of Actual vs. Predicted values with Wind Angle = 135

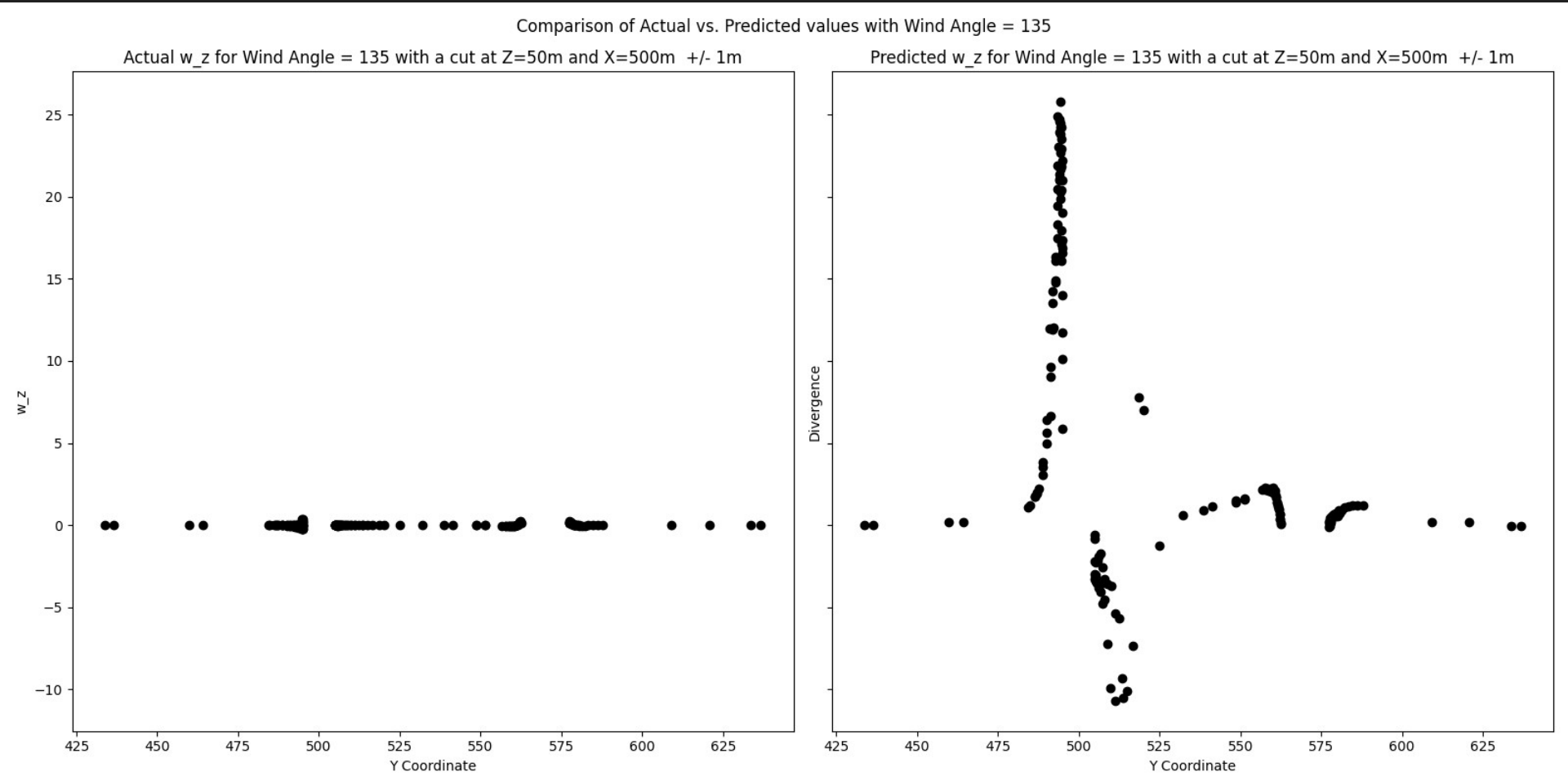




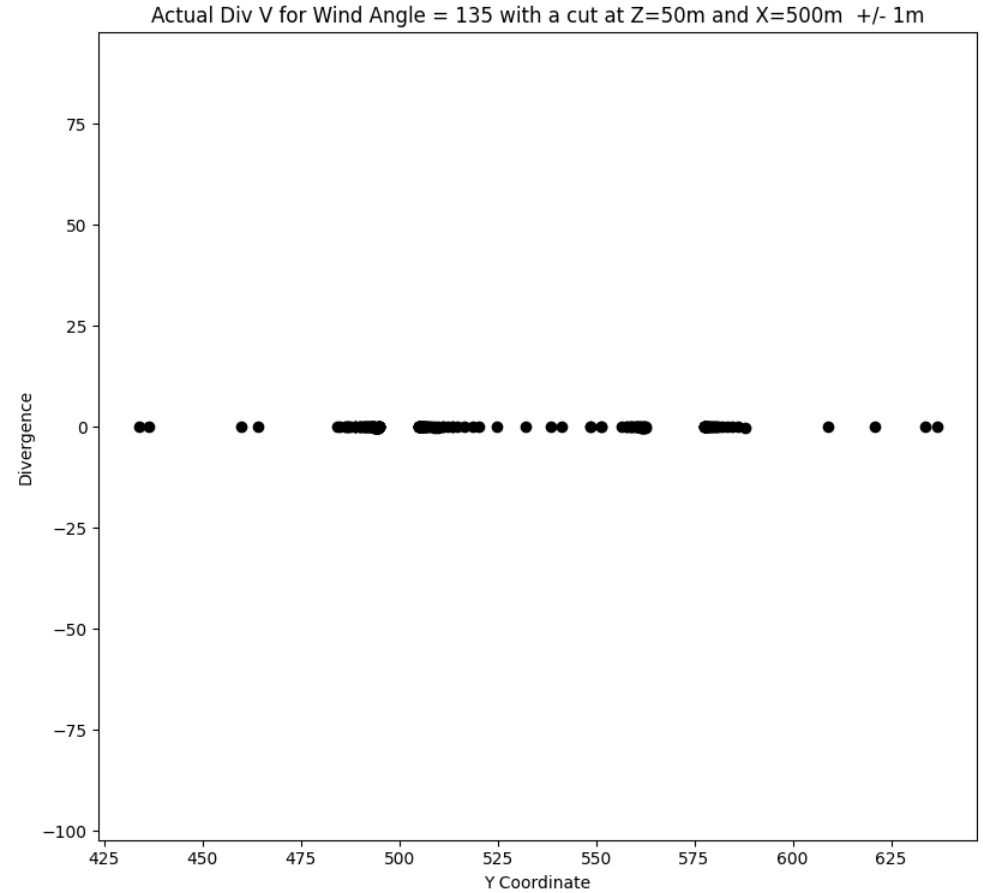
Comparison of Actual vs. Predicted values with Wind Angle = 135

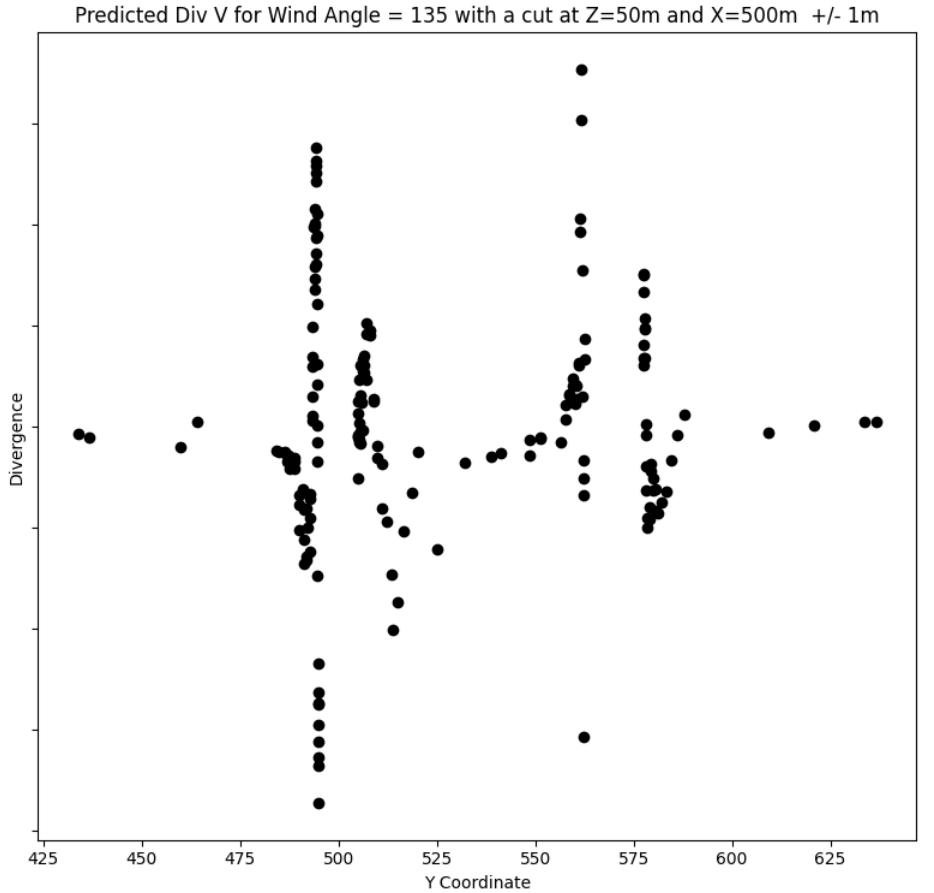




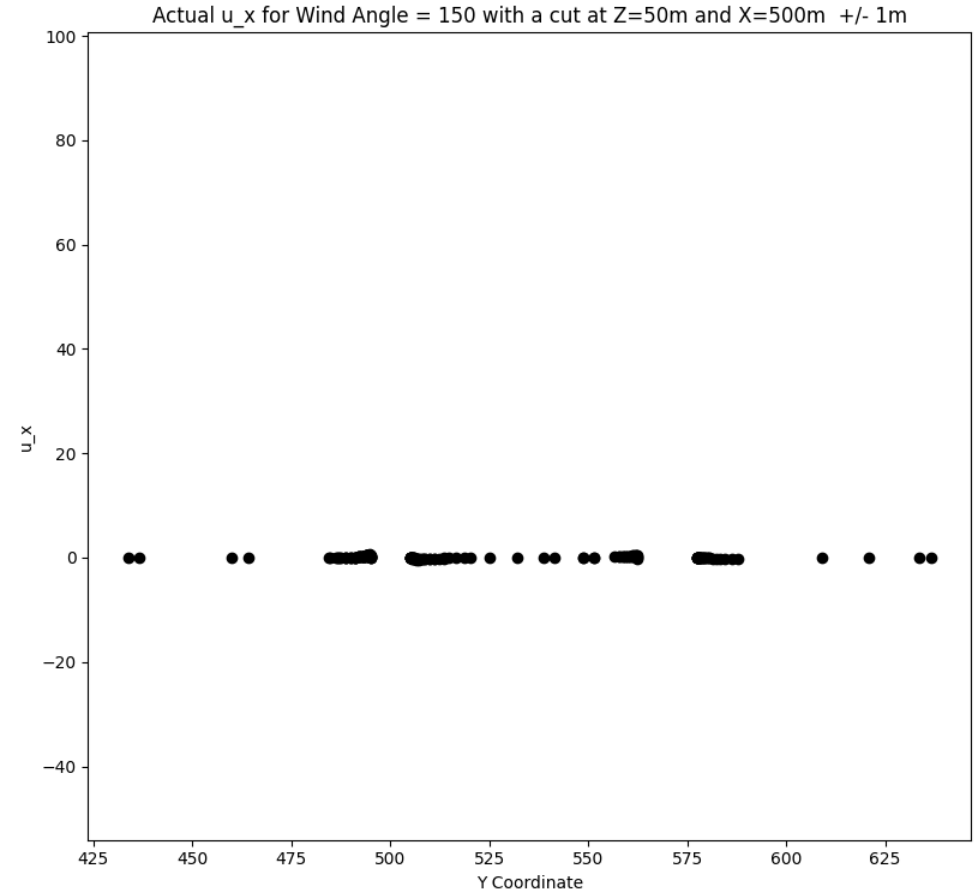

Comparison of Actual vs. Predicted values with Wind Angle = 135
Actual w_z for Wind Angle = 135 with a cut at Z=50m and X=500m +/- 1m
Predicted w_z for Wind Angle = 135 with a cut at Z=50m and X=500m +/- 1m
w_z
Divergence
Y Coordinate
Y Coordinate
25
20
15
10
5
0
−5
−10
425
450
475
500
525
550
575
600
625

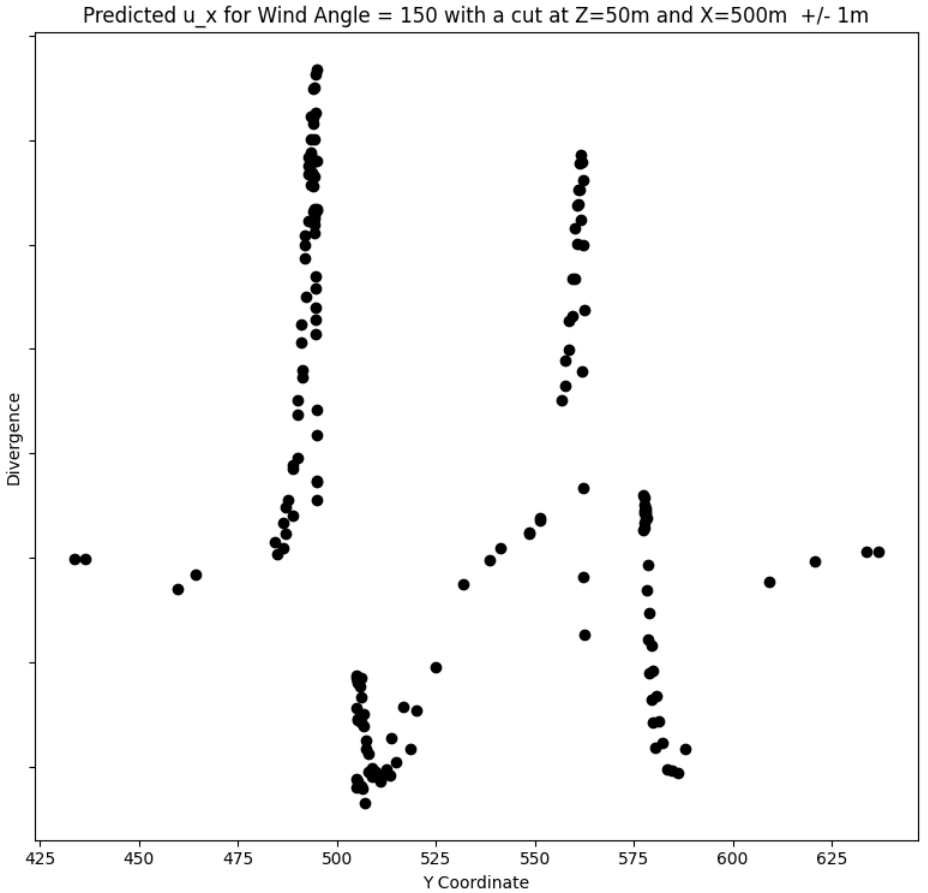
Comparison of Actual vs. Predicted values with Wind Angle = 135



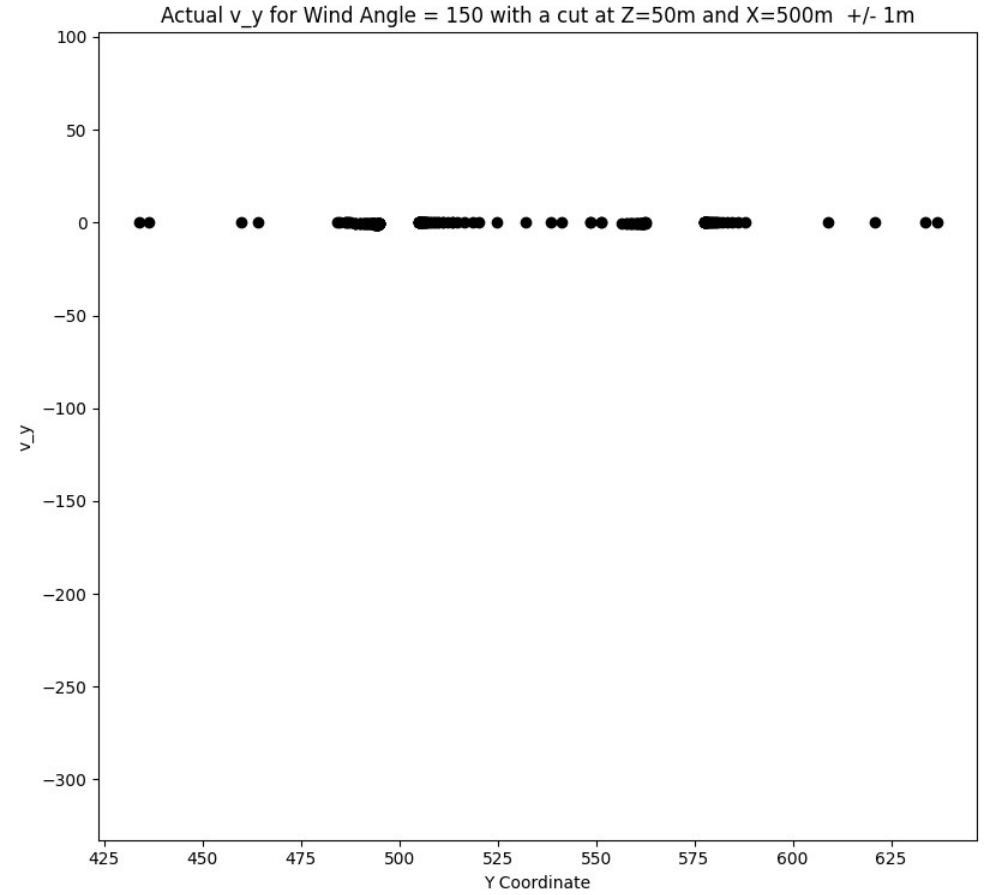


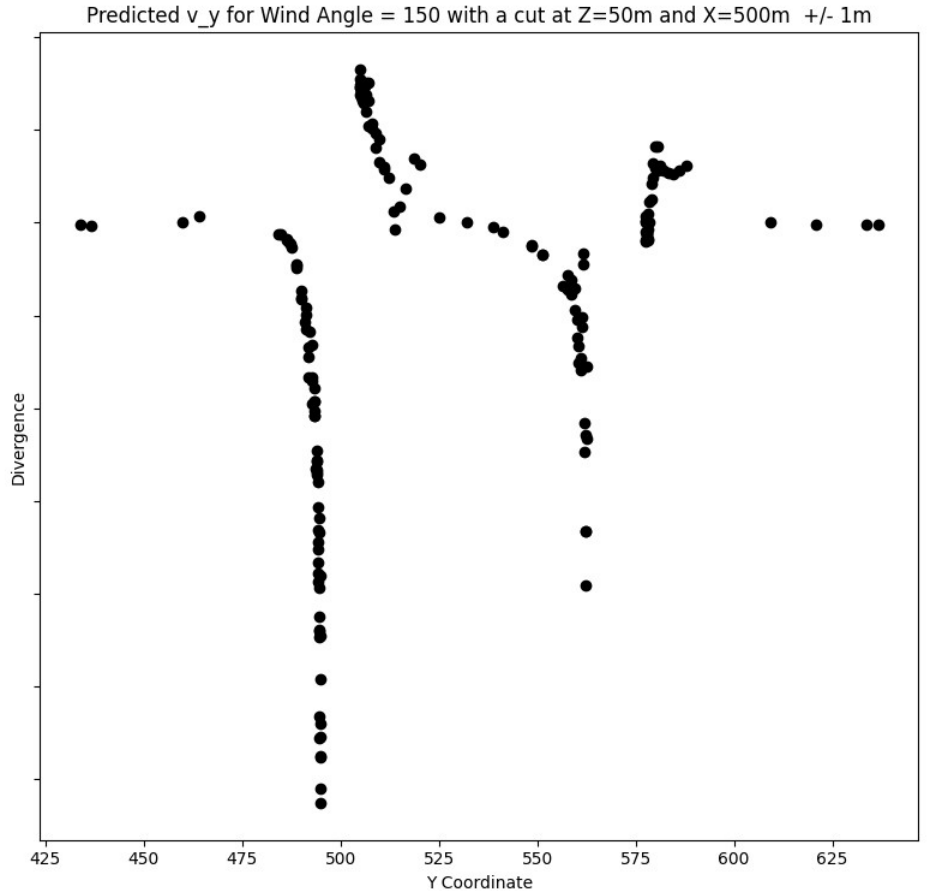
Comparison of Actual vs. Predicted values with Wind Angle = 150



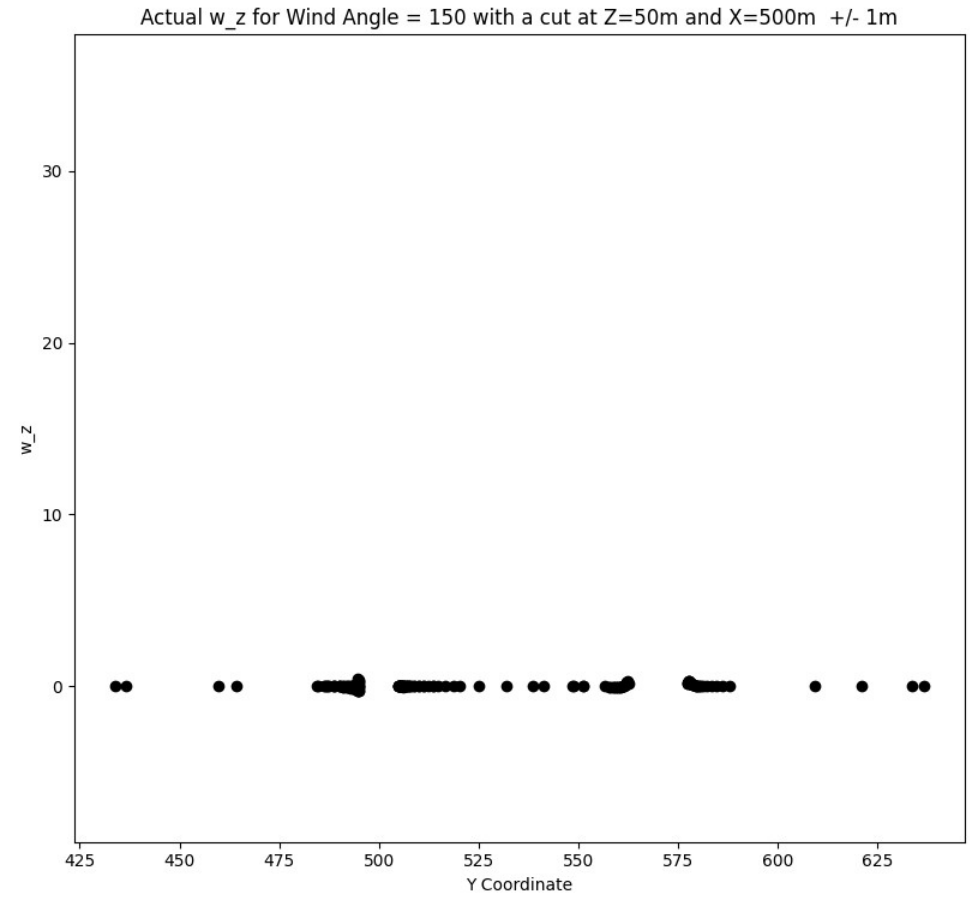


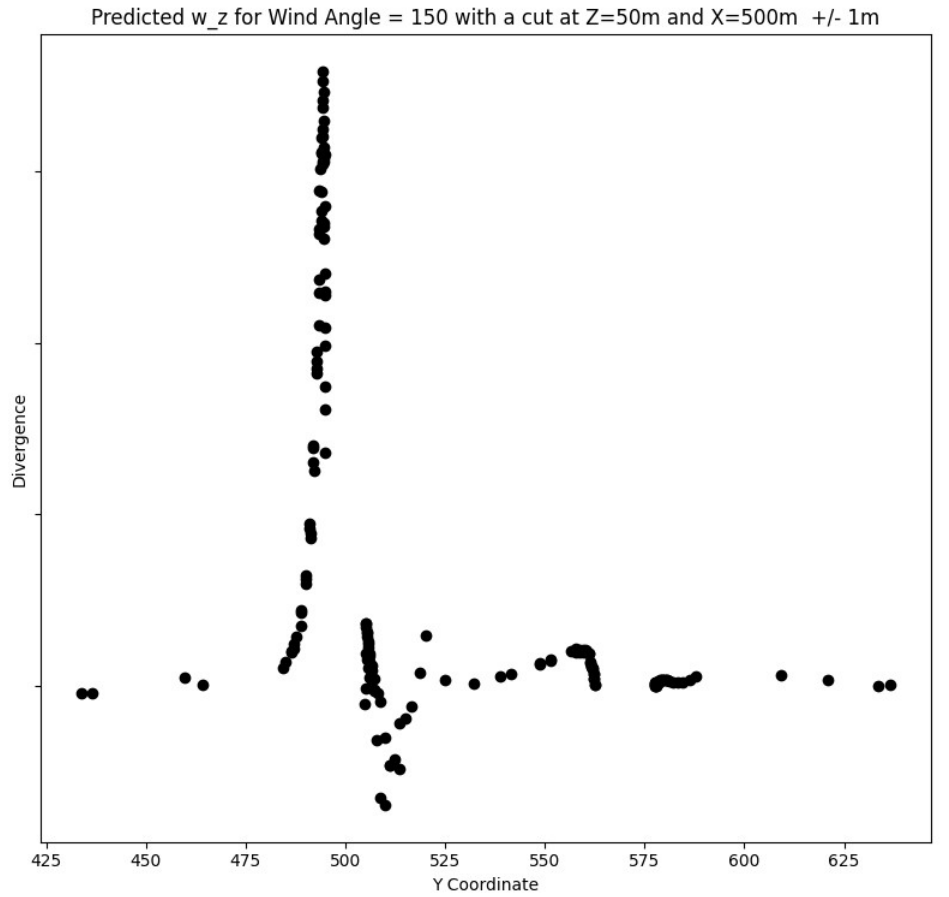
Comparison of Actual vs. Predicted values with Wind Angle = 150



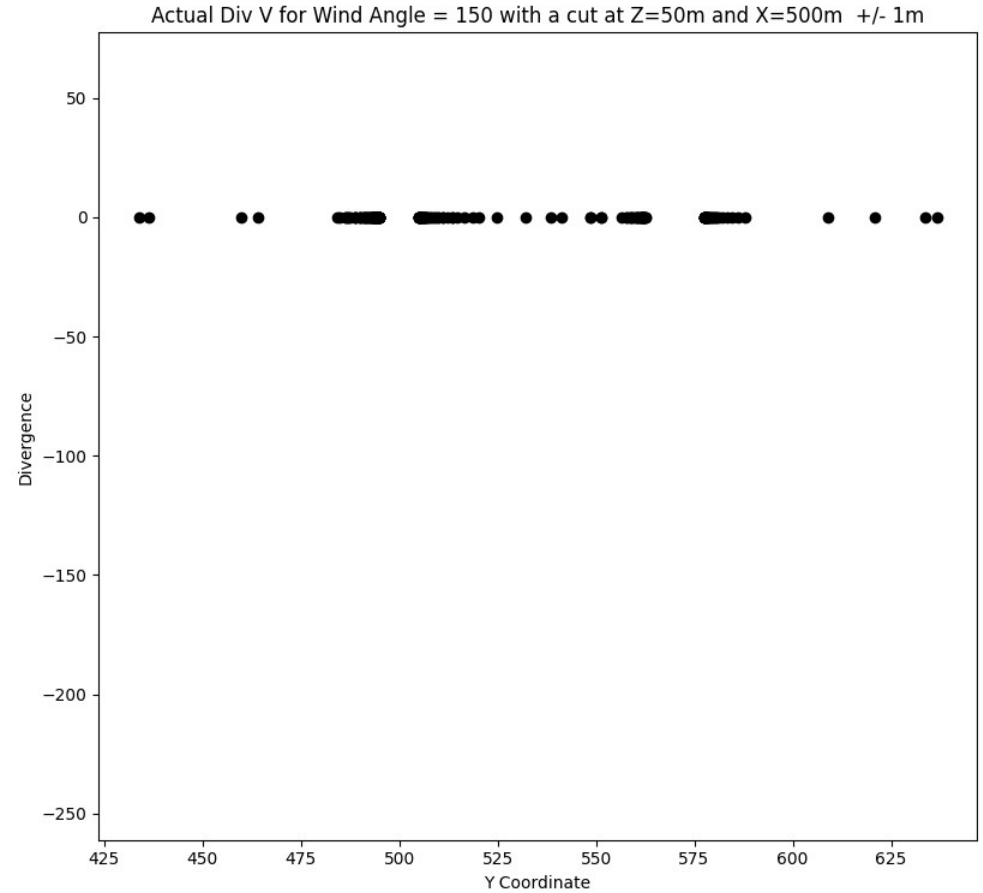


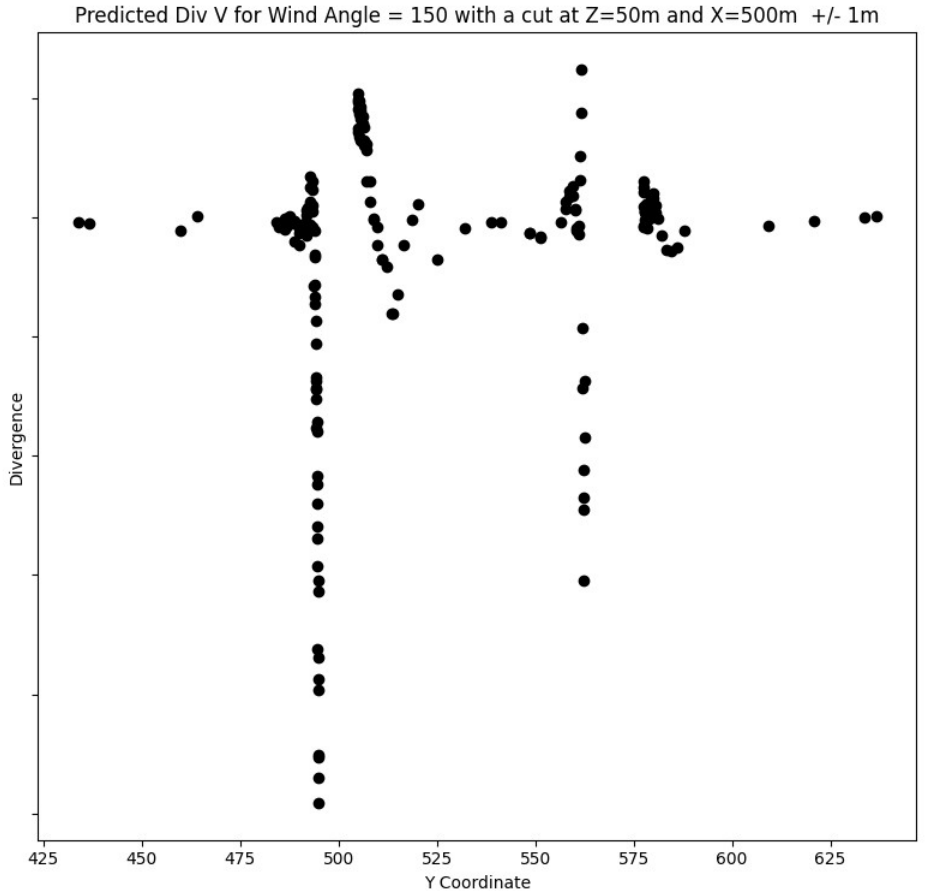
Comparison of Actual vs. Predicted values with Wind Angle = 150



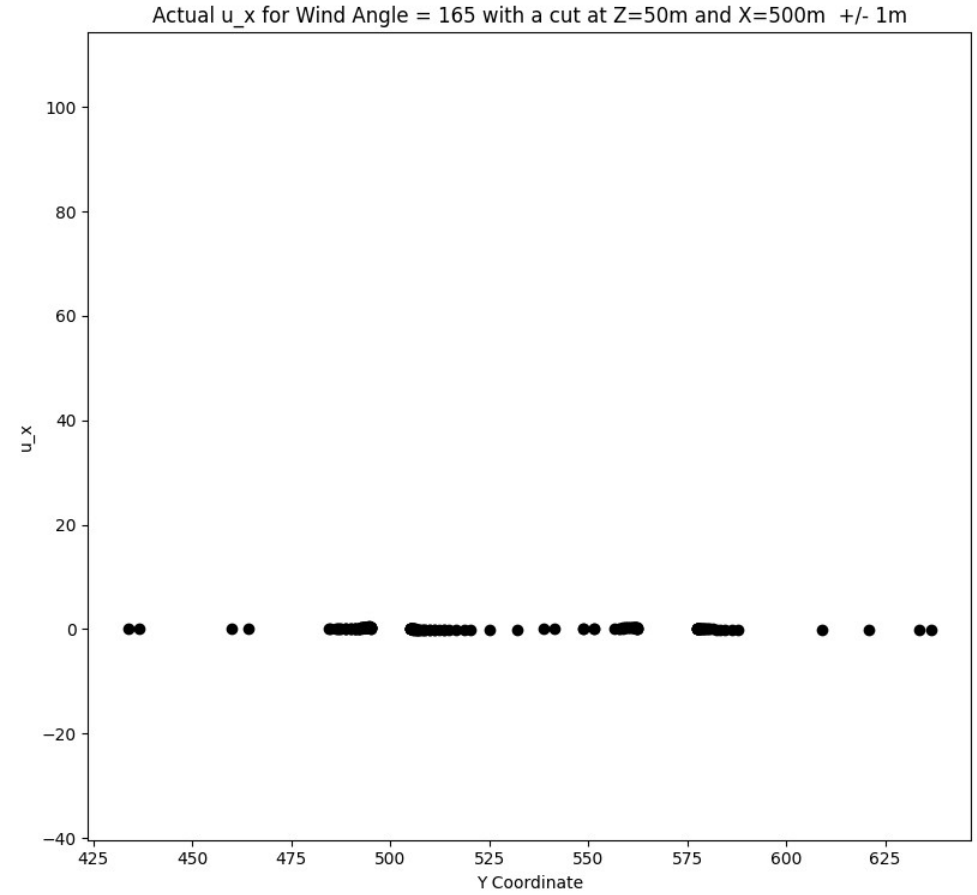


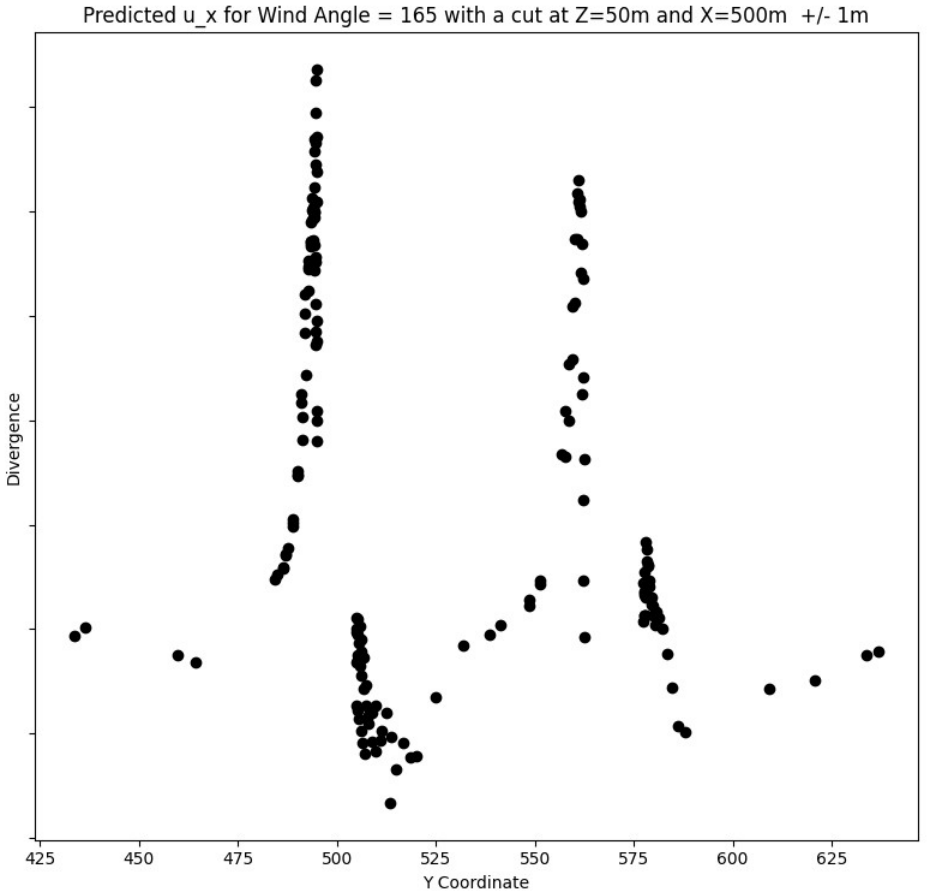
Comparison of Actual vs. Predicted values with Wind Angle = 150



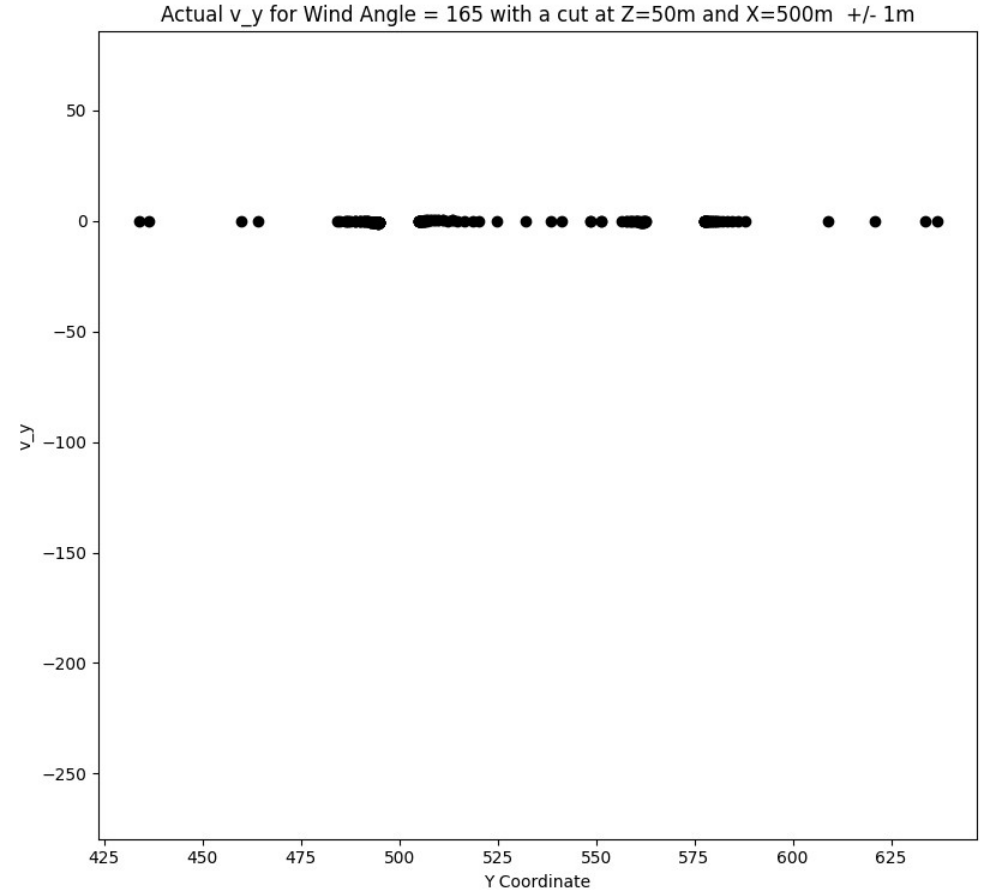


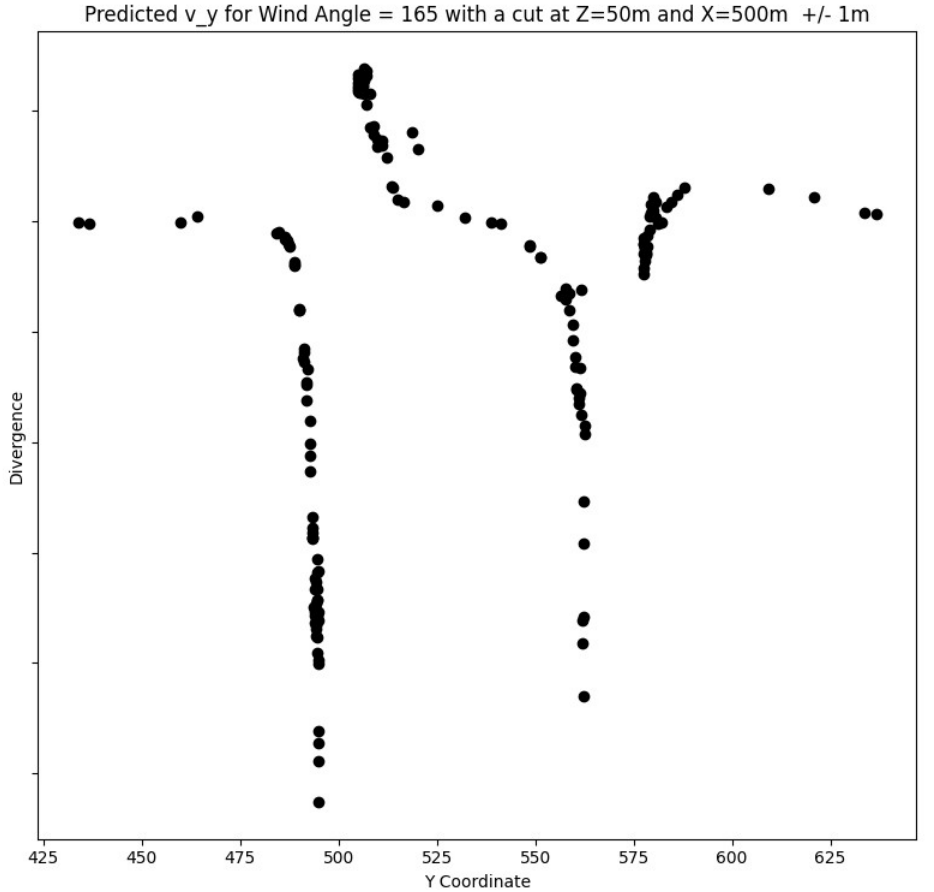
Comparison of Actual vs. Predicted values with Wind Angle = 165



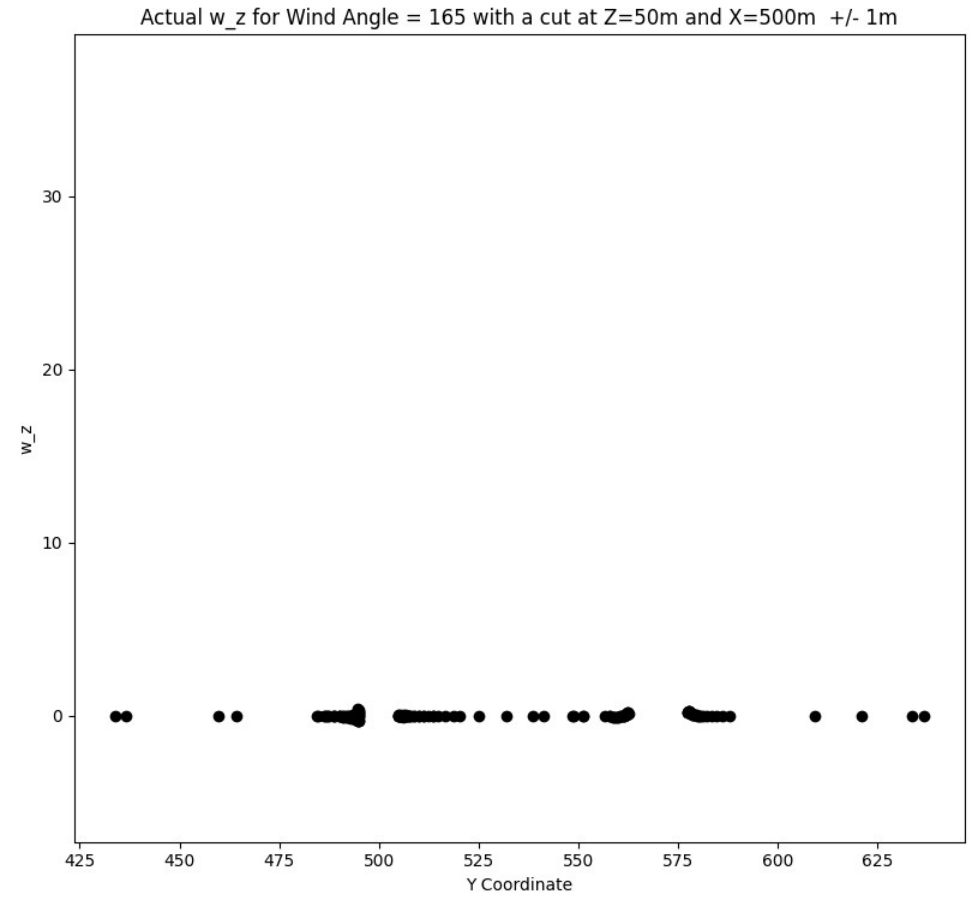


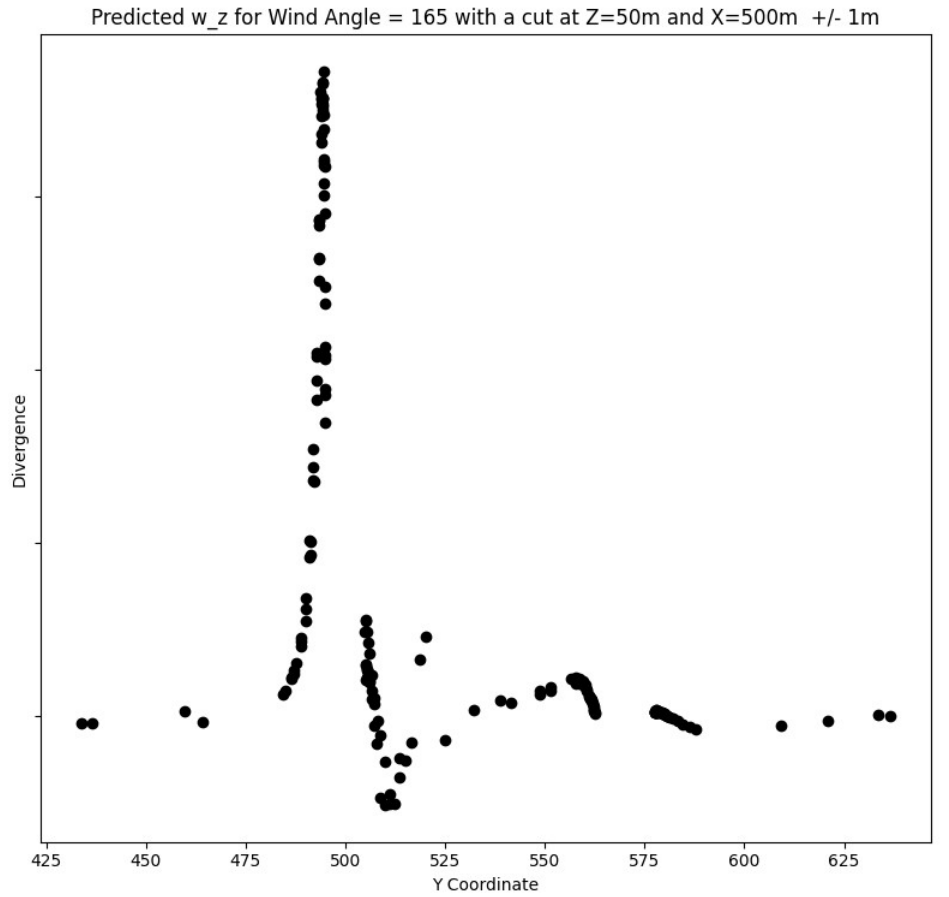
Comparison of Actual vs. Predicted values with Wind Angle = 165



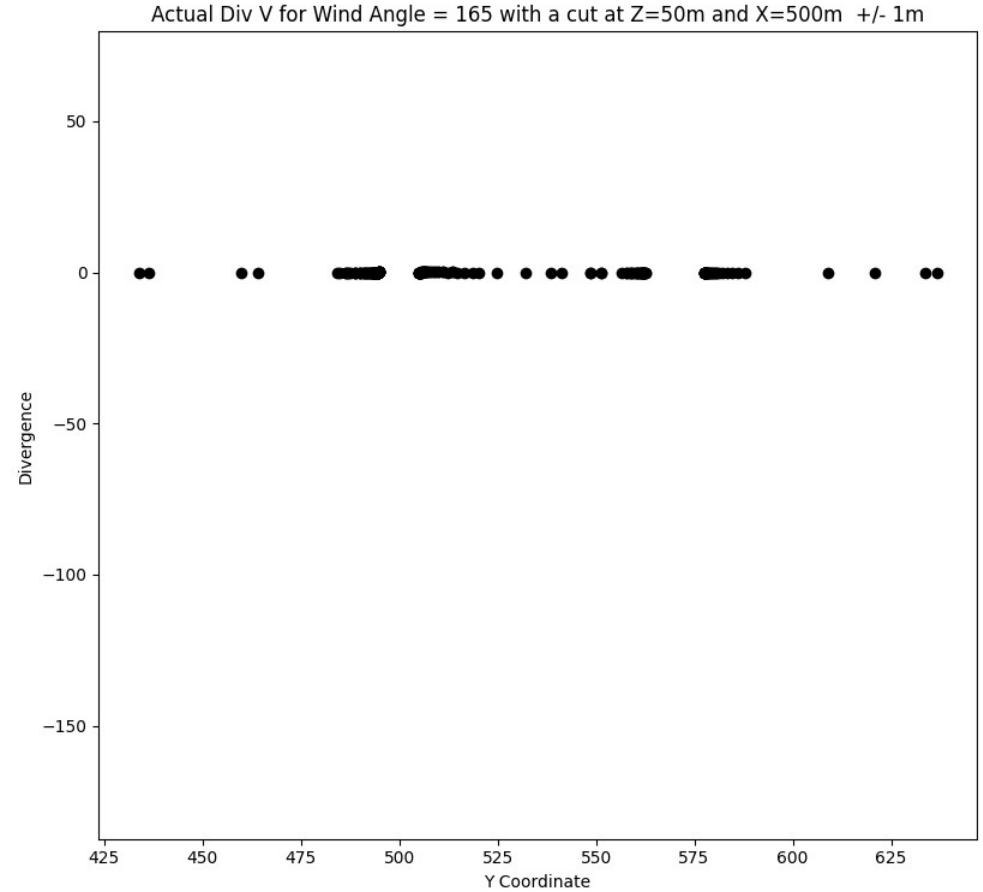


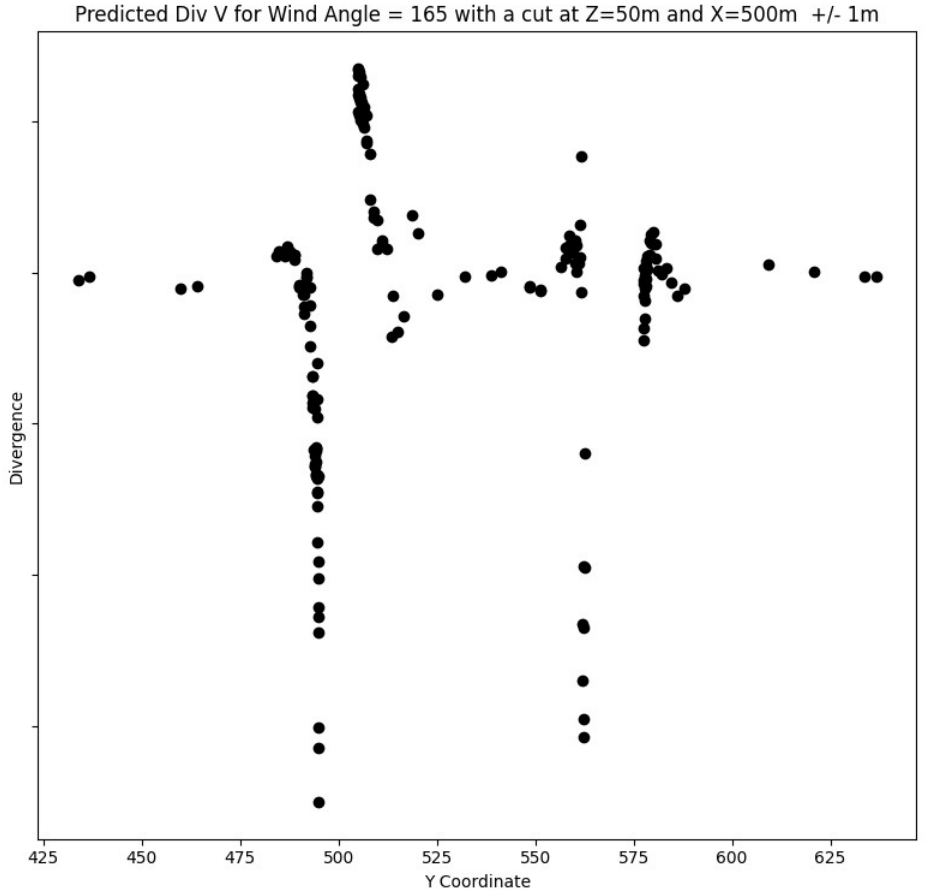
Comparison of Actual vs. Predicted values with Wind Angle = 165



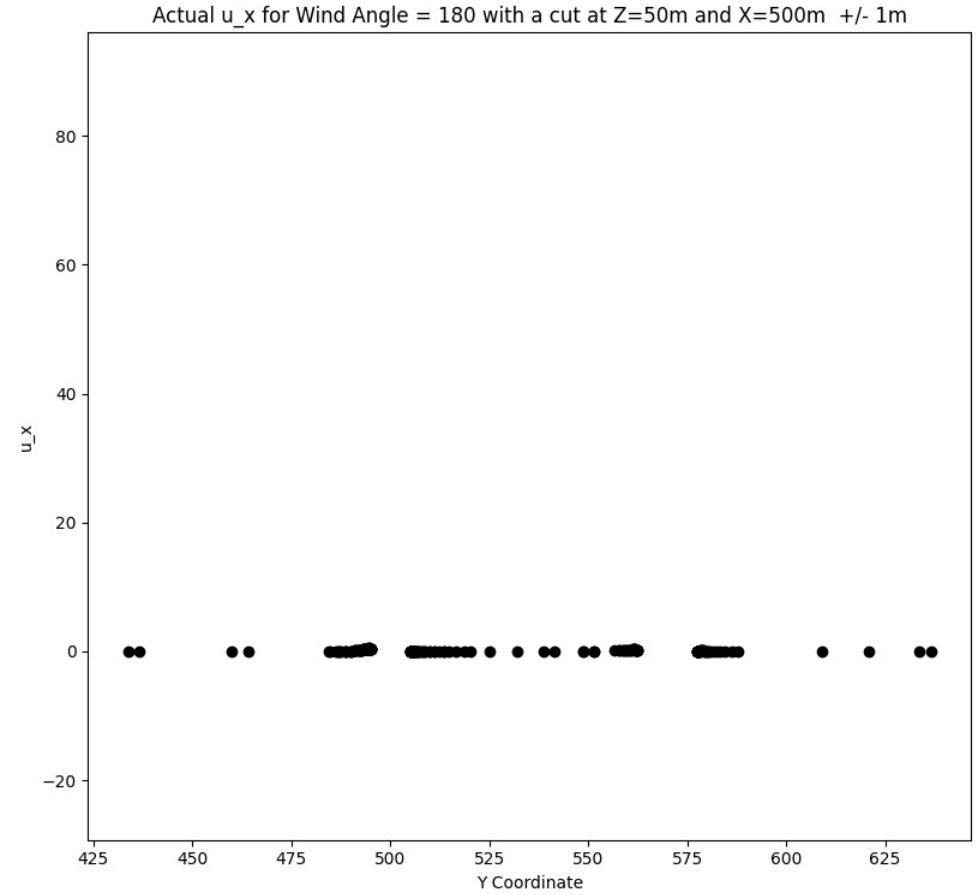


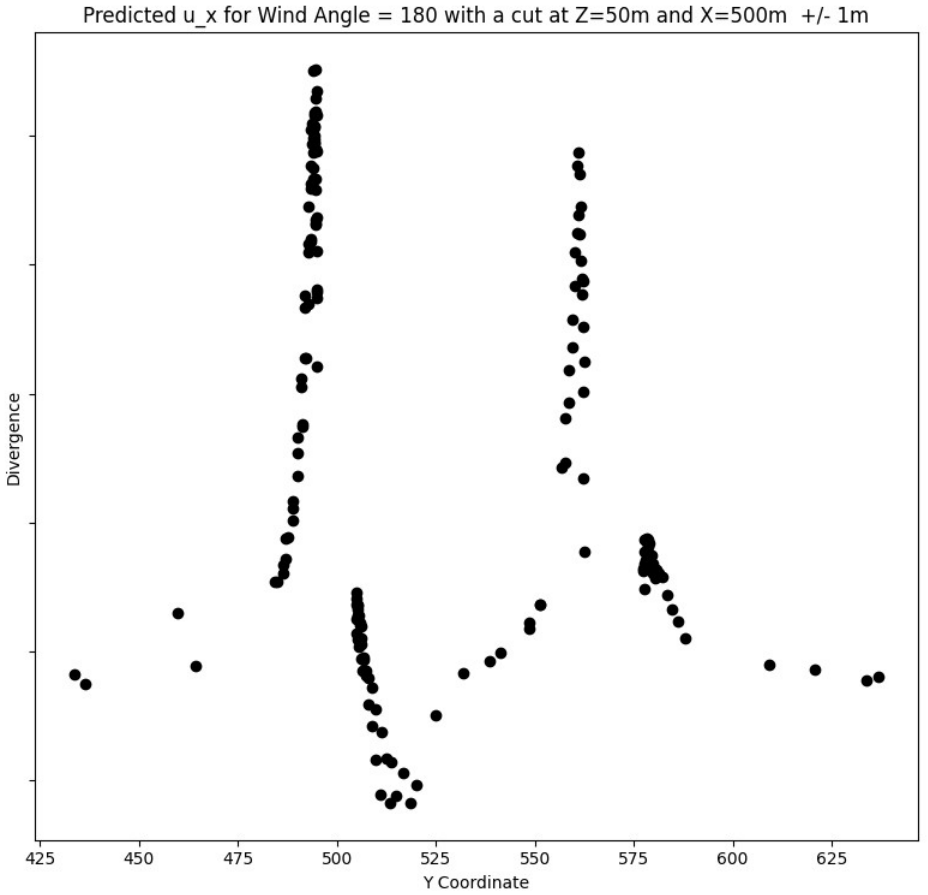
Comparison of Actual vs. Predicted values with Wind Angle = 165



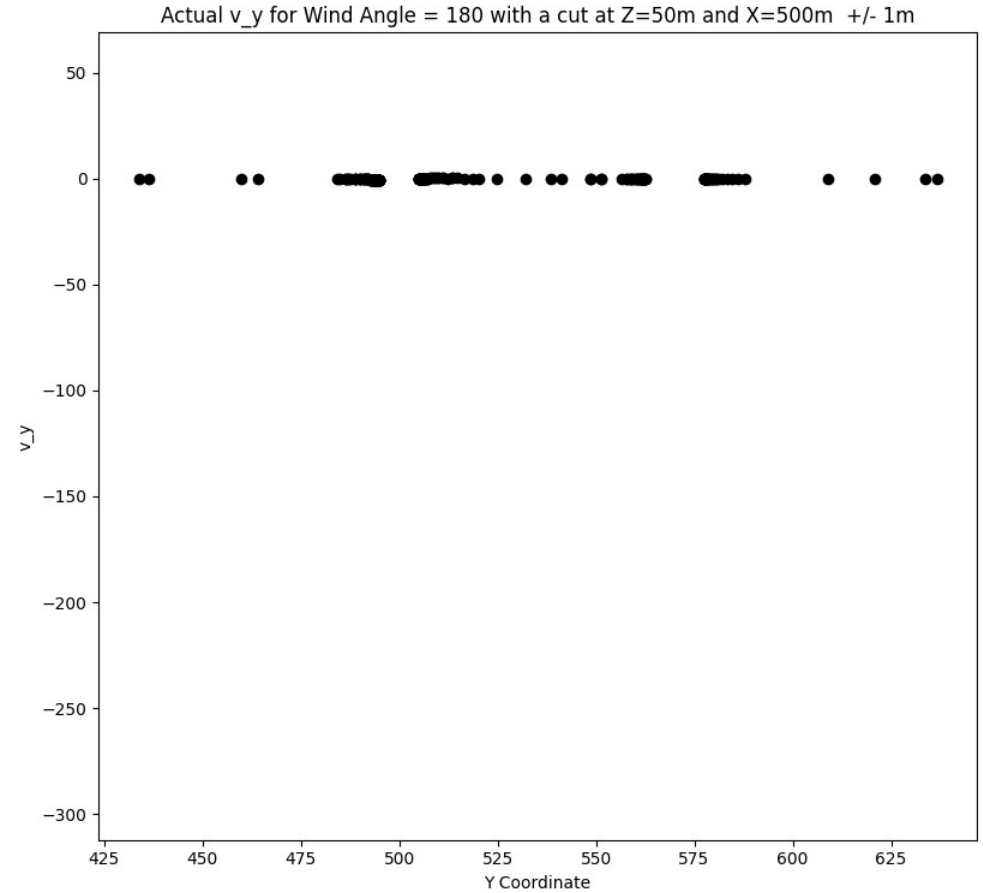


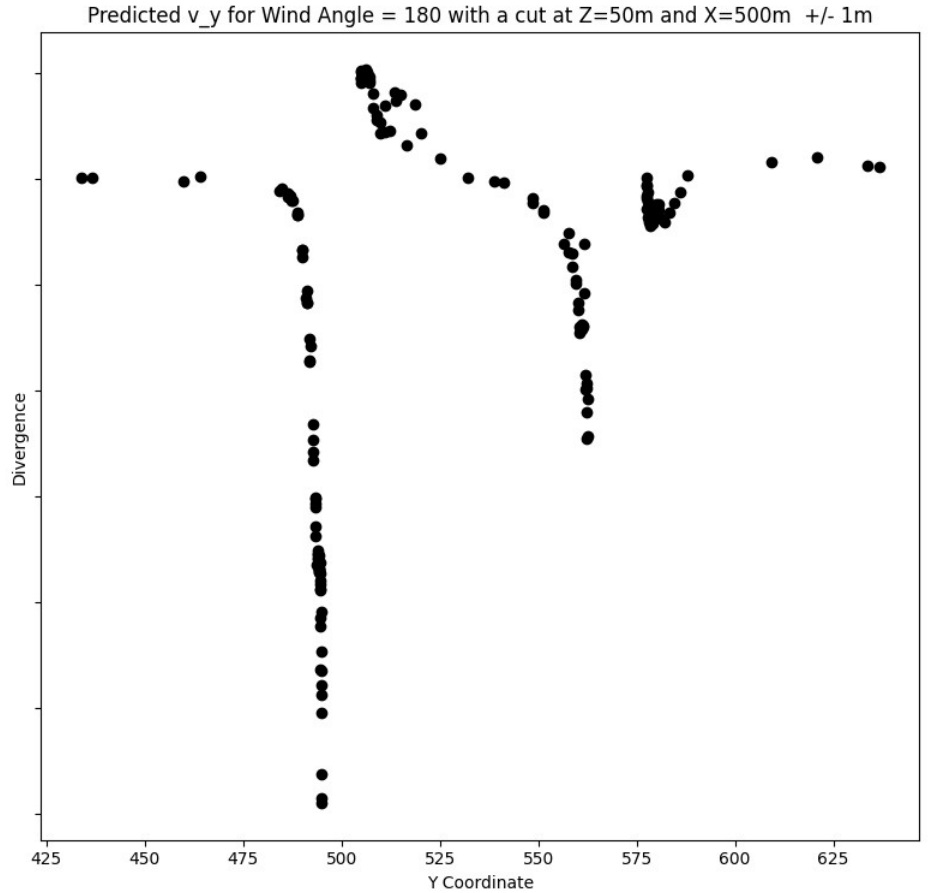
Comparison of Actual vs. Predicted values with Wind Angle = 180



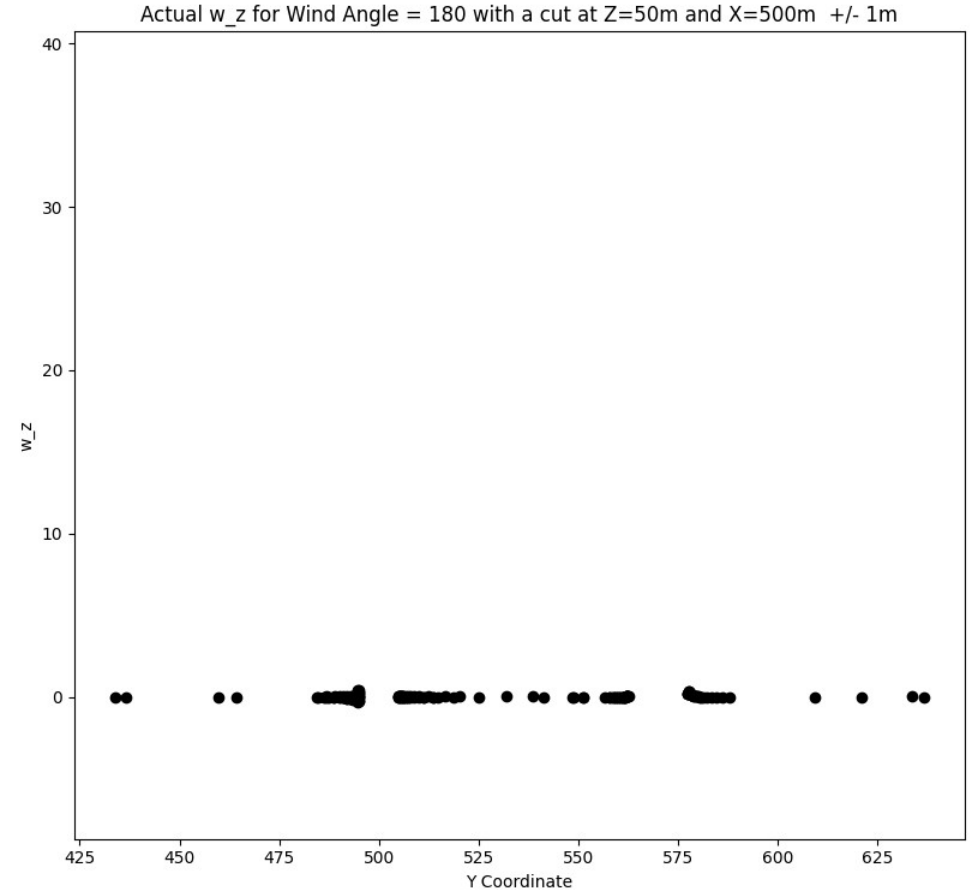


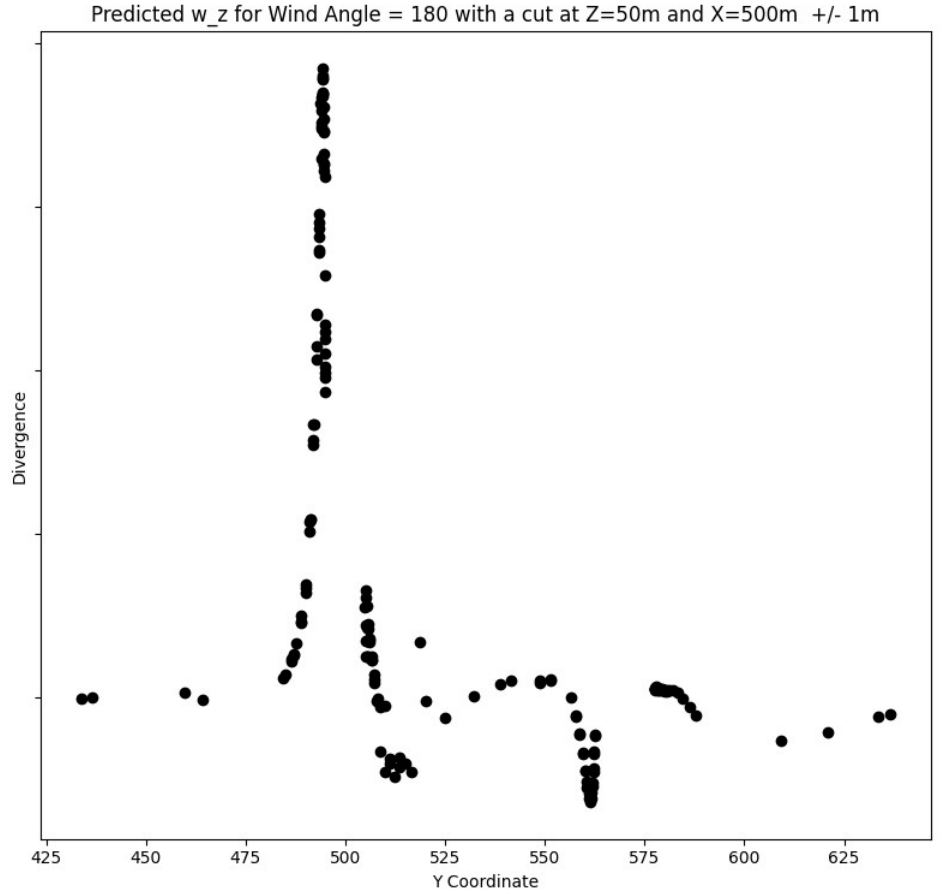
Comparison of Actual vs. Predicted values with Wind Angle = 180



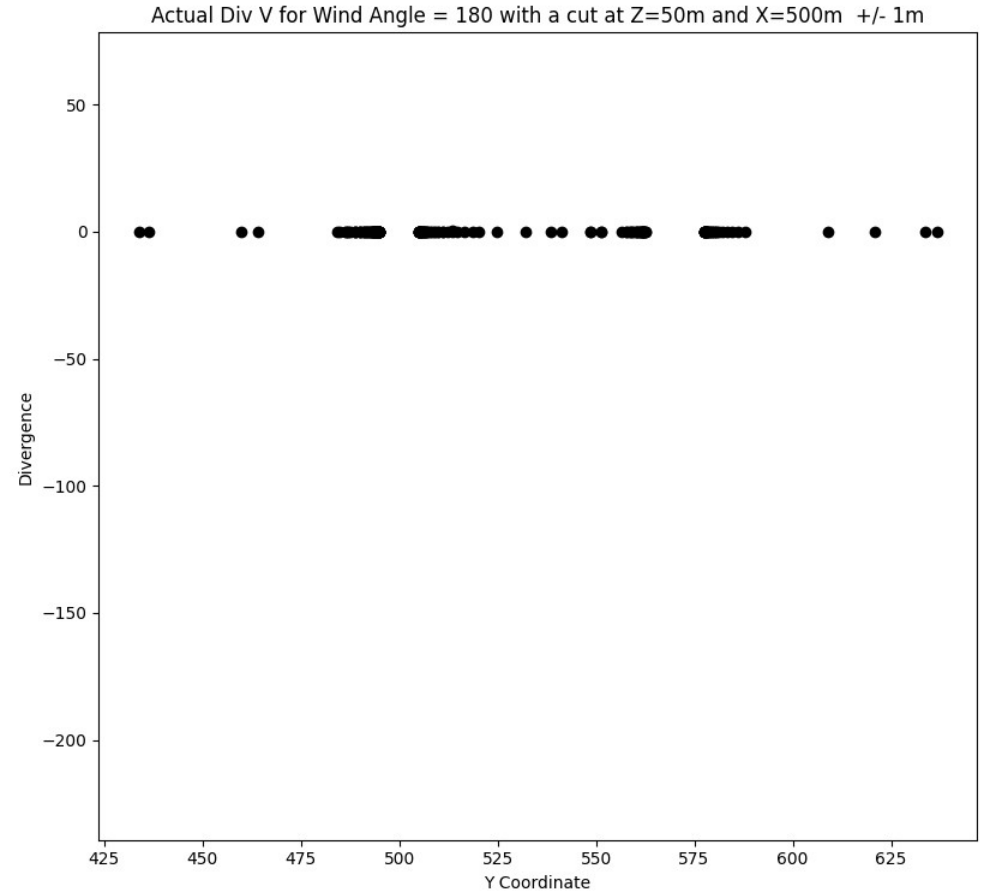


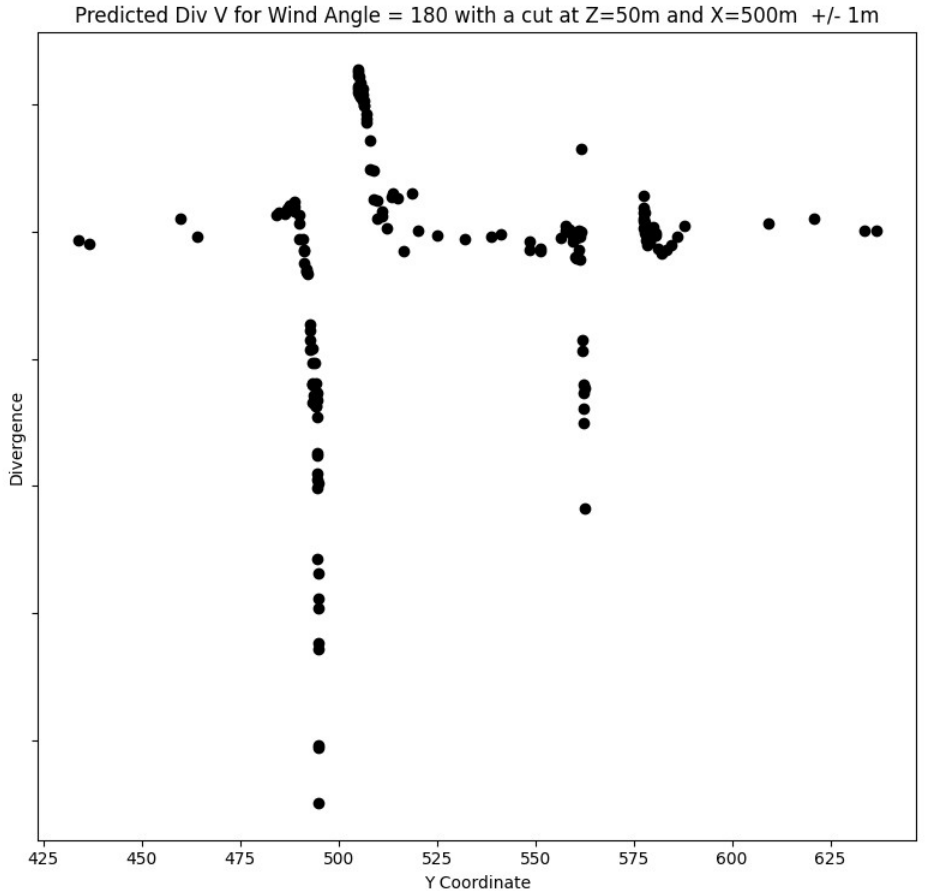
Comparison of Actual vs. Predicted values with Wind Angle = 180



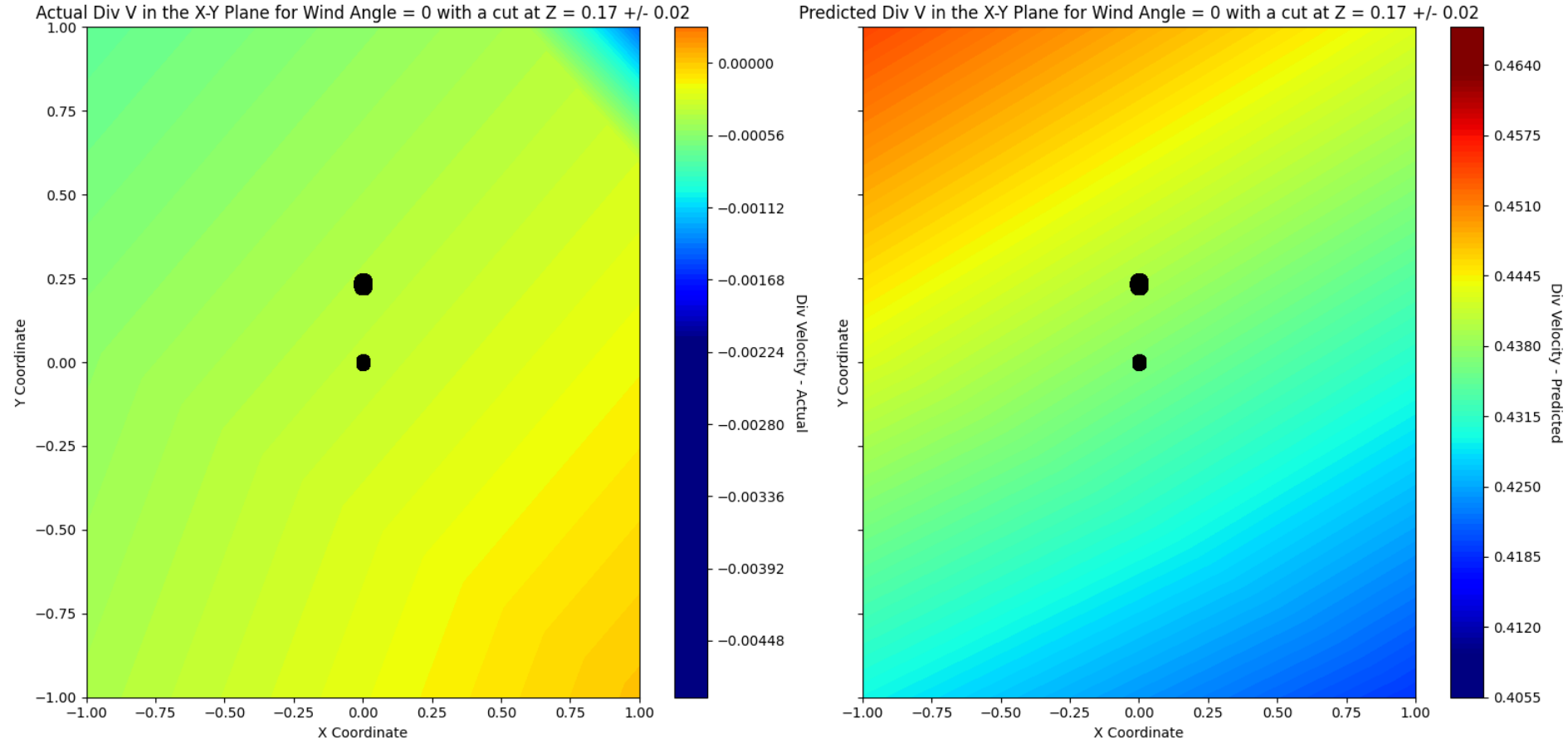


Comparison of Actual vs. Predicted values with Wind Angle = 180

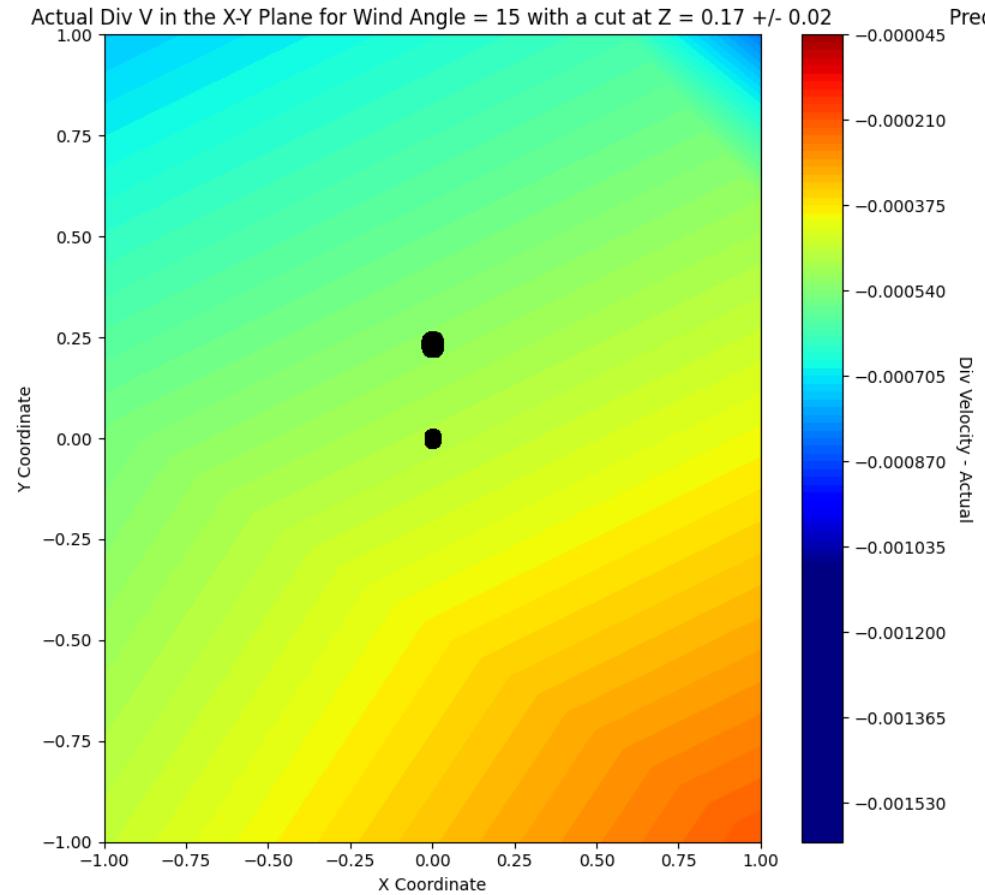


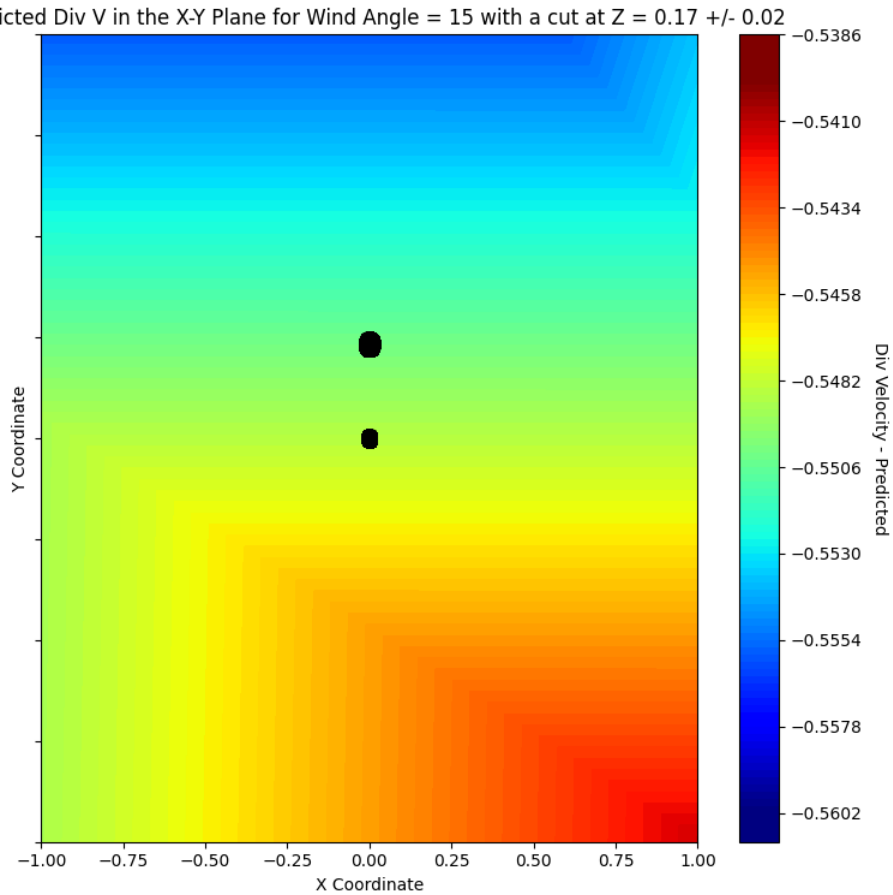


Comparison of Actual vs. Predicted values with Wind Angle = 0 in the X-Y Plane with a cut at Z = 0.17 +/- 0.02

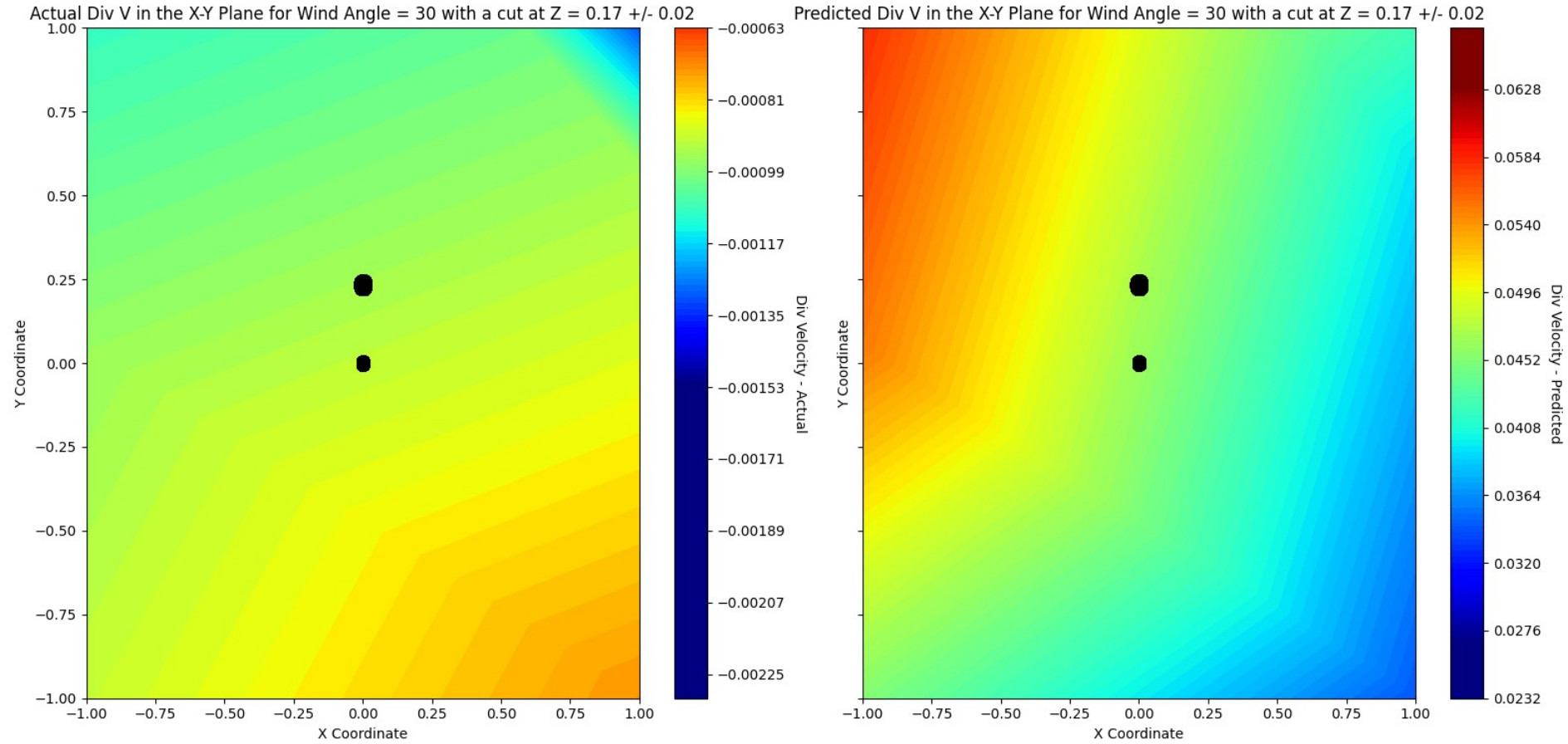


Comparison of Actual vs. Predicted values with Wind Angle = 15 in the X-Y Plane with a cut at Z = 0.17 +/- 0.02

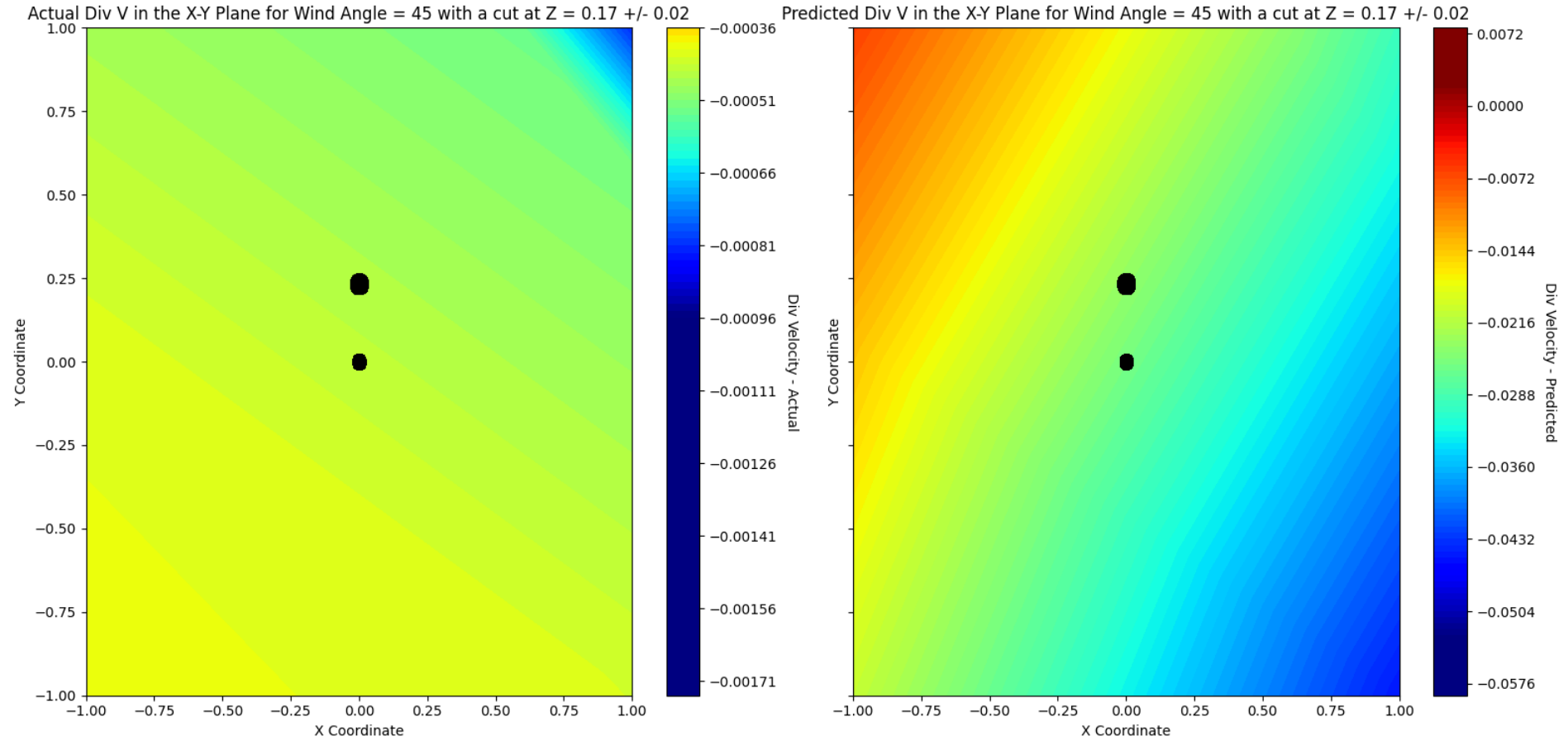




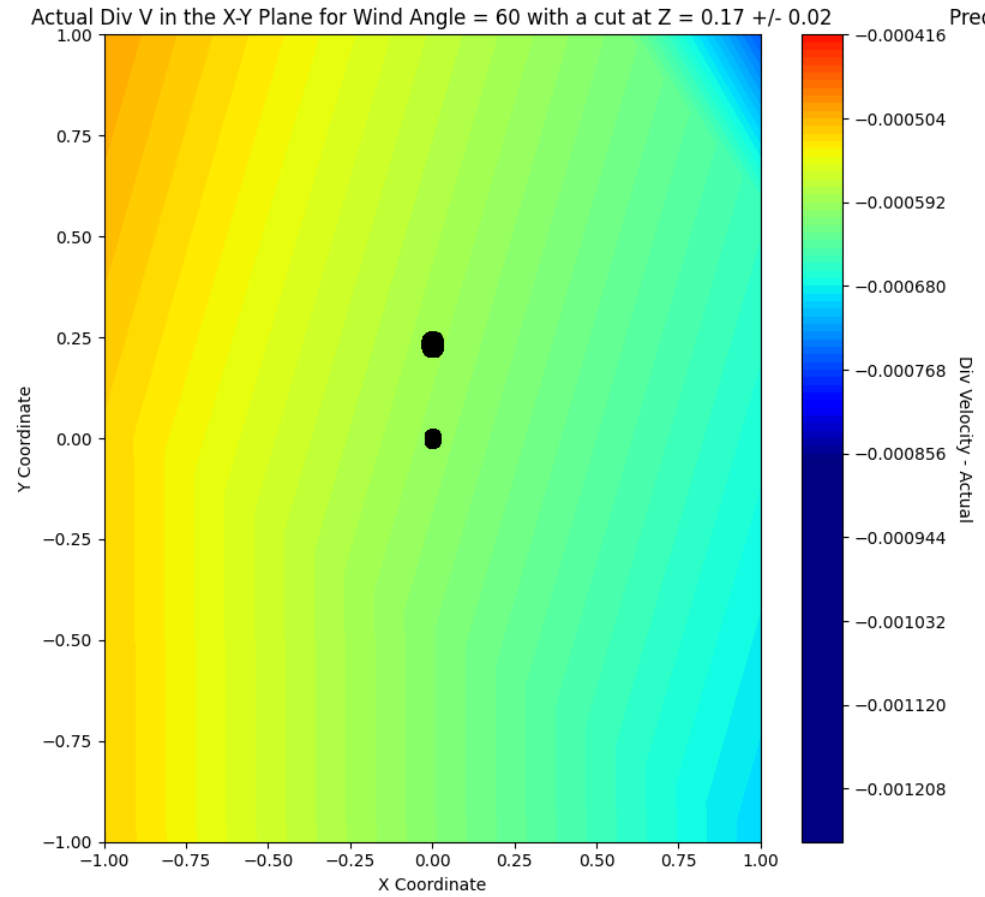
Comparison of Actual vs. Predicted values with Wind Angle = 30 in the X-Y Plane with a cut at Z = 0.17 +/- 0.02

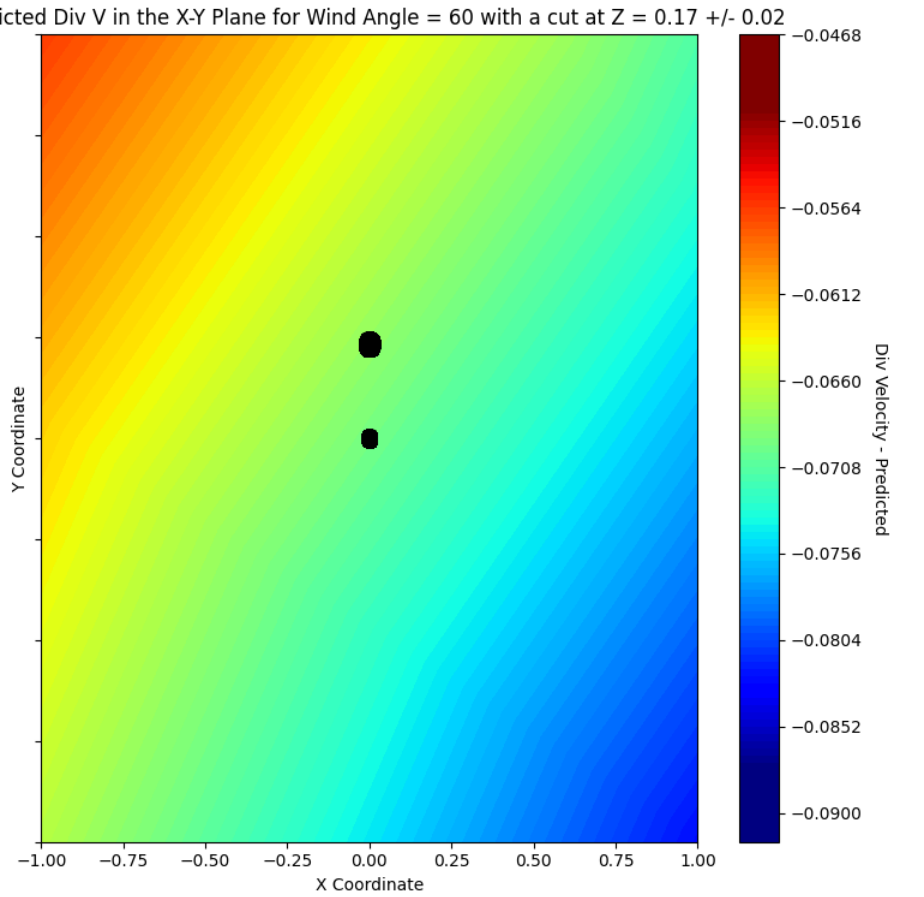


Comparison of Actual vs. Predicted values with Wind Angle = 45 in the X-Y Plane with a cut at Z = 0.17 +/- 0.02

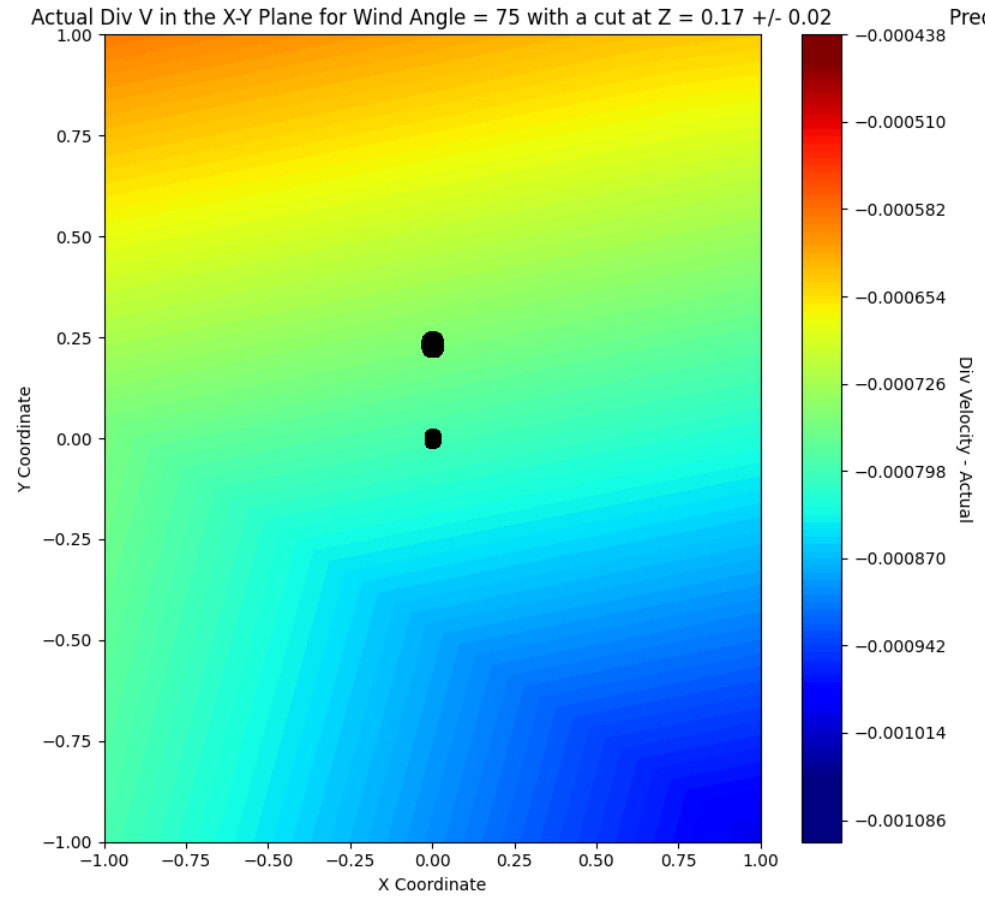


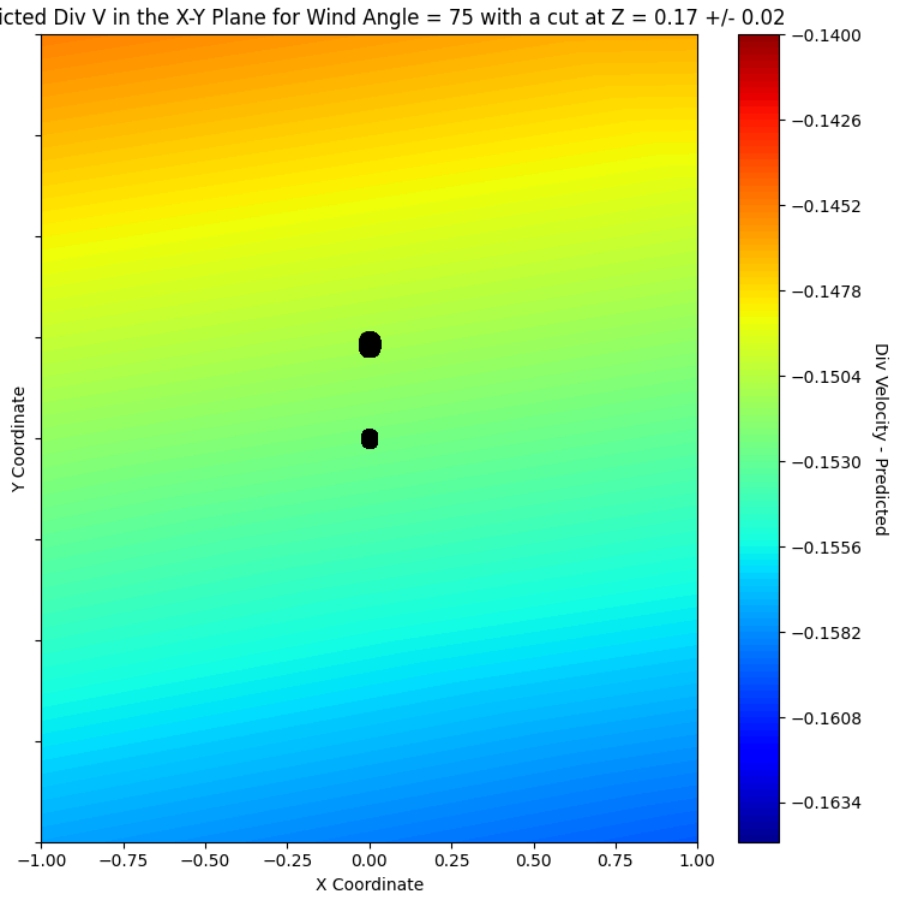
Comparison of Actual vs. Predicted values with Wind Angle = 60 in the X-Y Plane with a cut at Z = 0.17 +/- 0.02



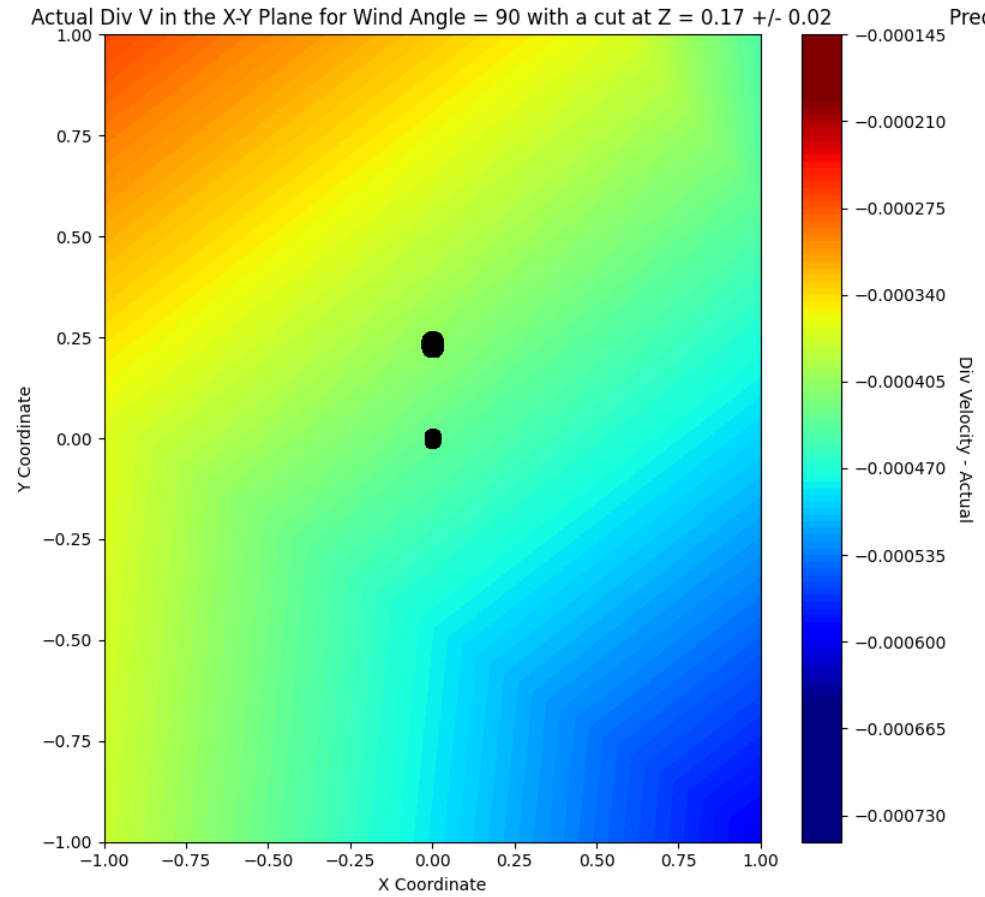


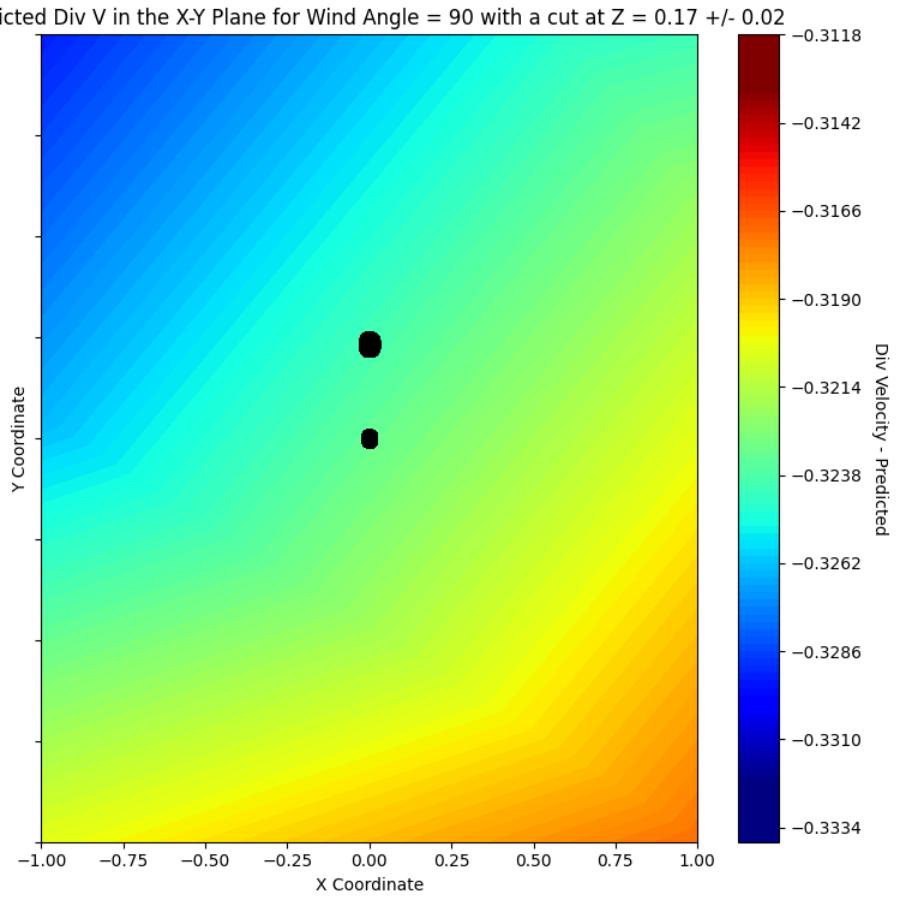
Comparison of Actual vs. Predicted values with Wind Angle = 75 in the X-Y Plane with a cut at Z = 0.17 +/- 0.02



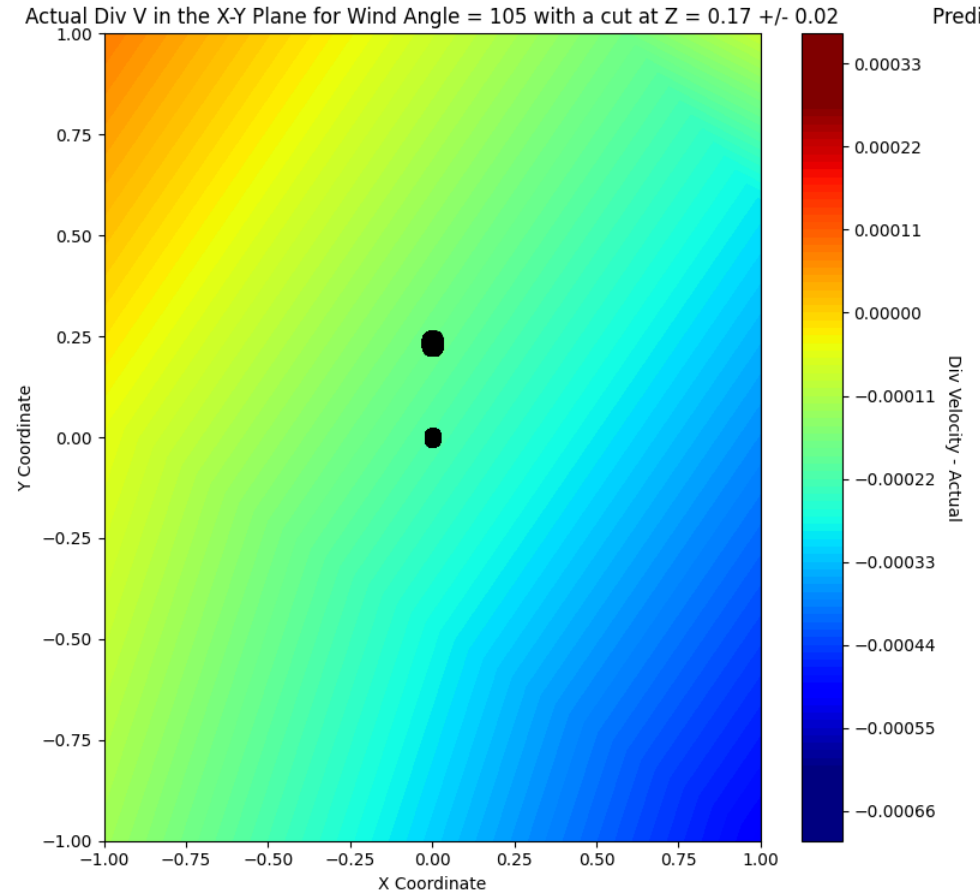


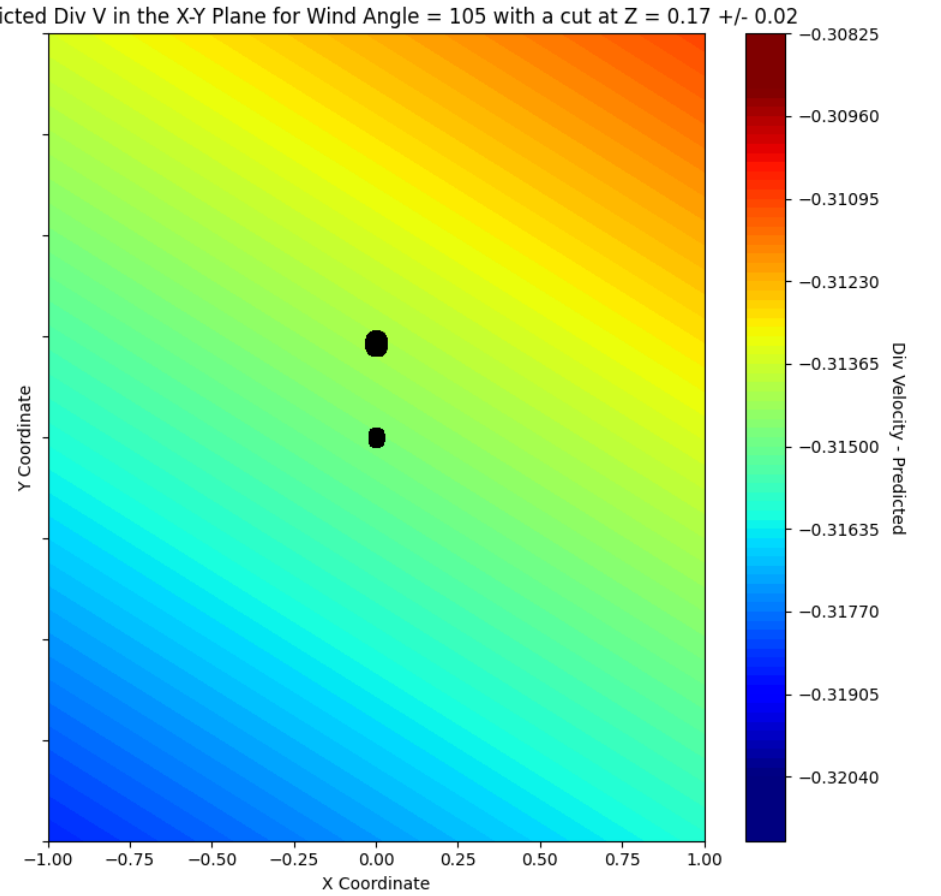
Comparison of Actual vs. Predicted values with Wind Angle = 90 in the X-Y Plane with a cut at Z = 0.17 +/- 0.02



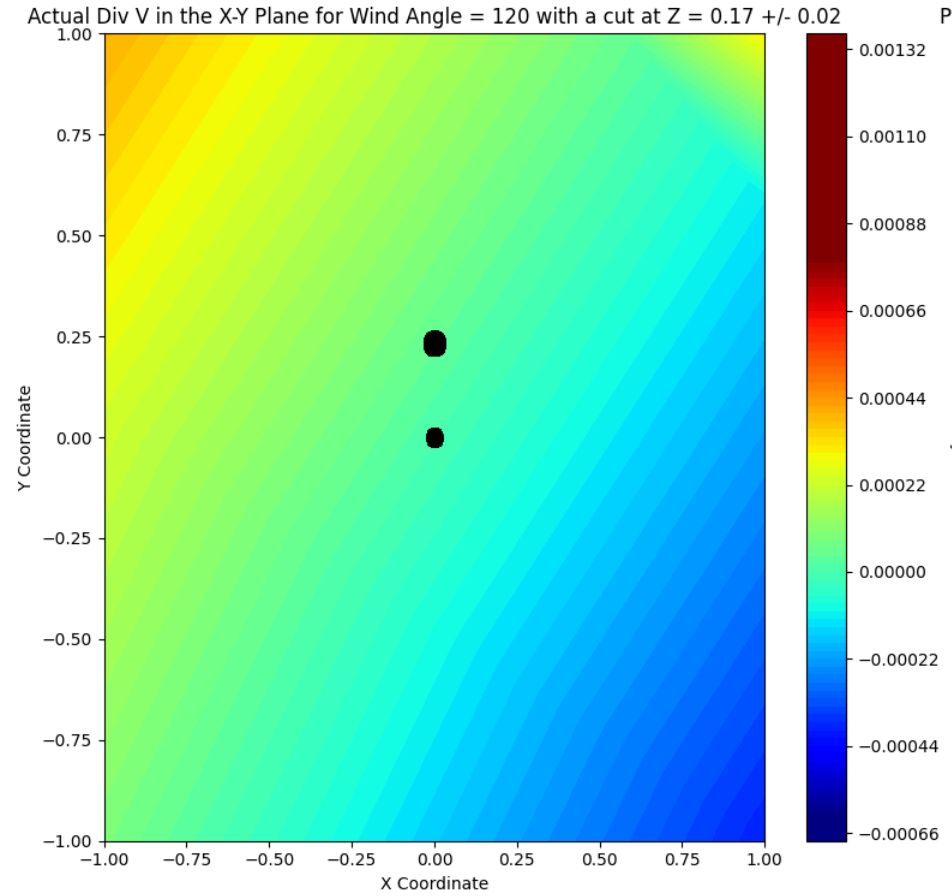


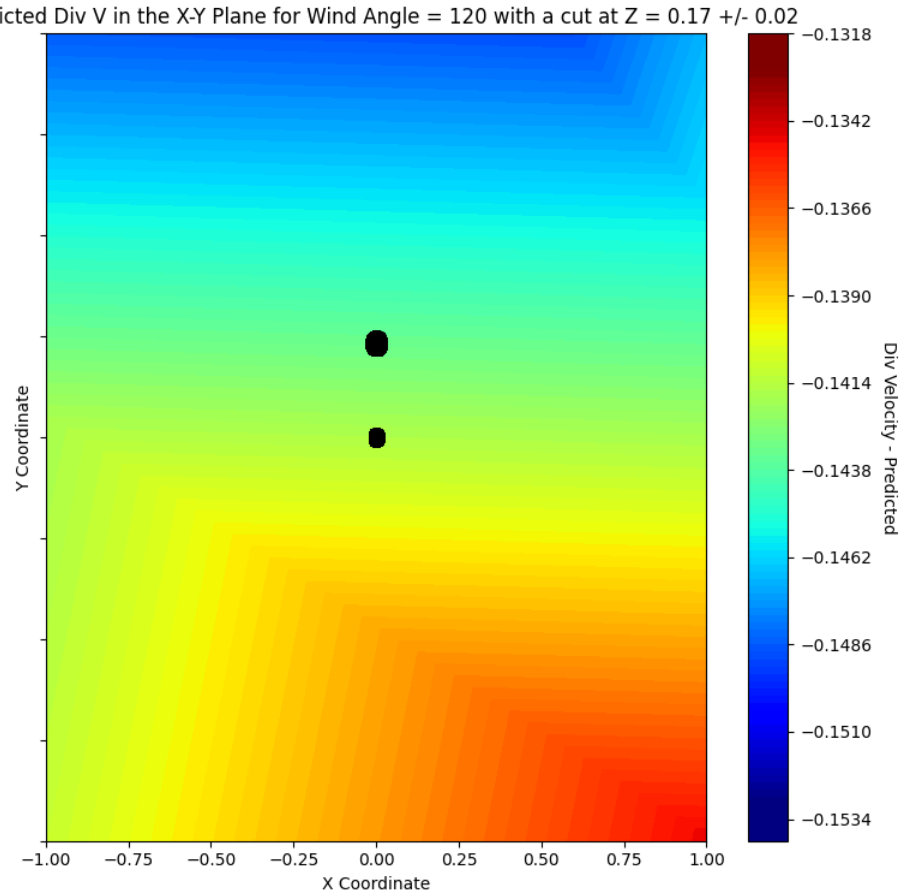
Comparison of Actual vs. Predicted values with Wind Angle = 105 in the X-Y Plane with a cut at Z = 0.17 +/- 0.02



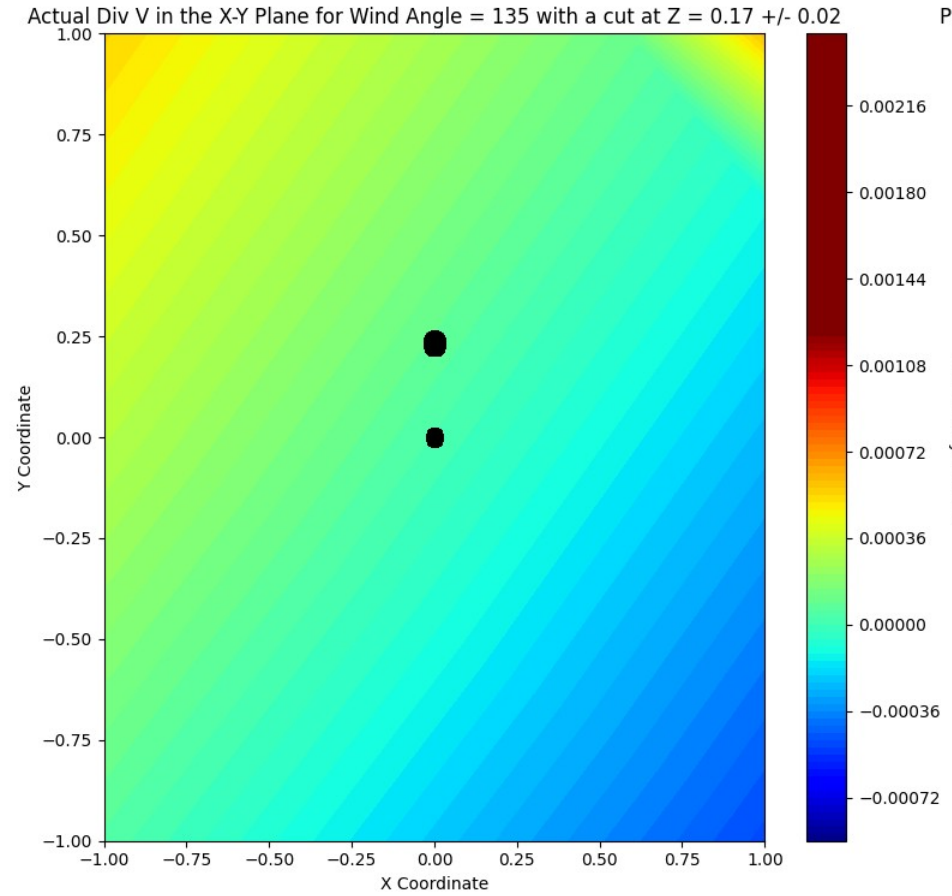


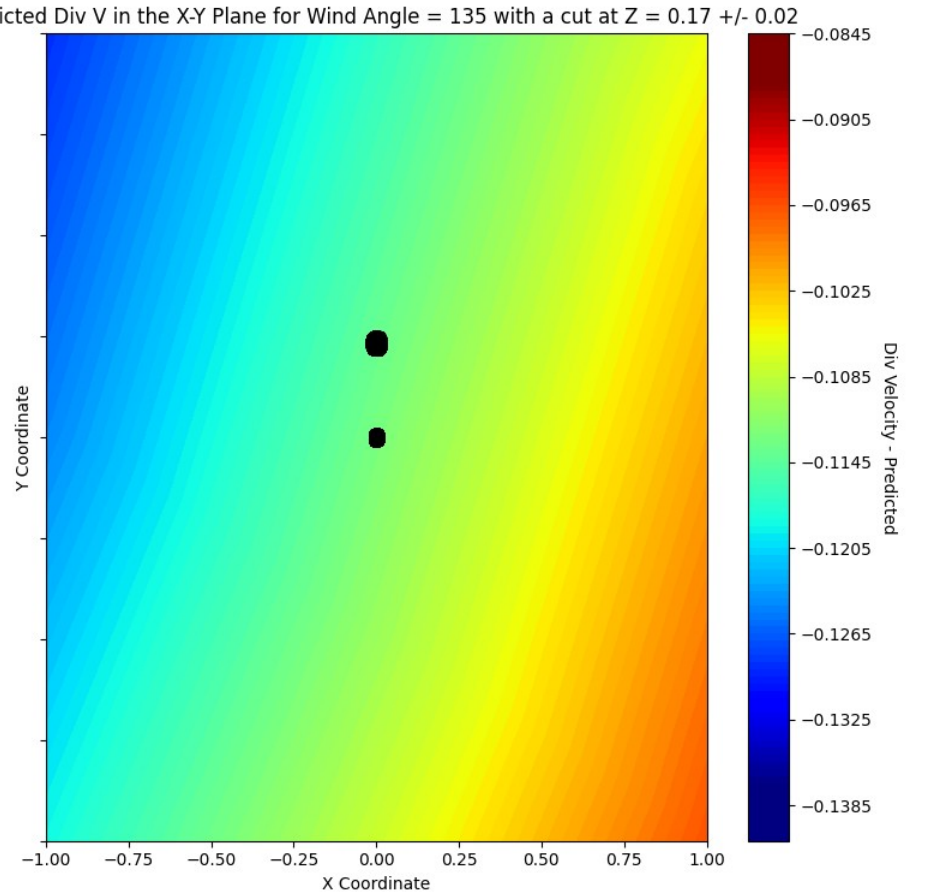
Comparison of Actual vs. Predicted values with Wind Angle = 120 in the X-Y Plane with a cut at Z = 0.17 +/- 0.02



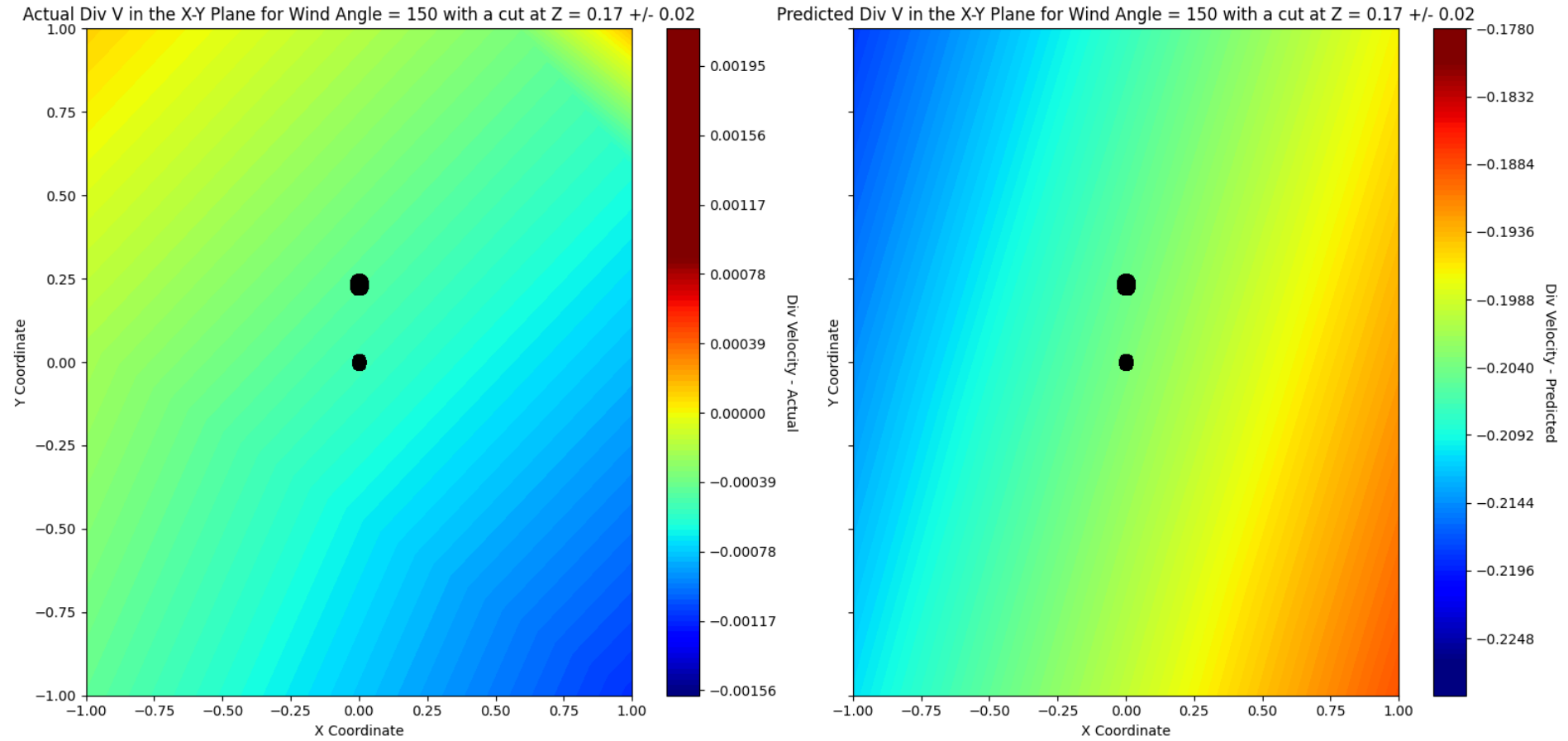


Comparison of Actual vs. Predicted values with Wind Angle = 135 in the X-Y Plane with a cut at Z = 0.17 +/- 0.02

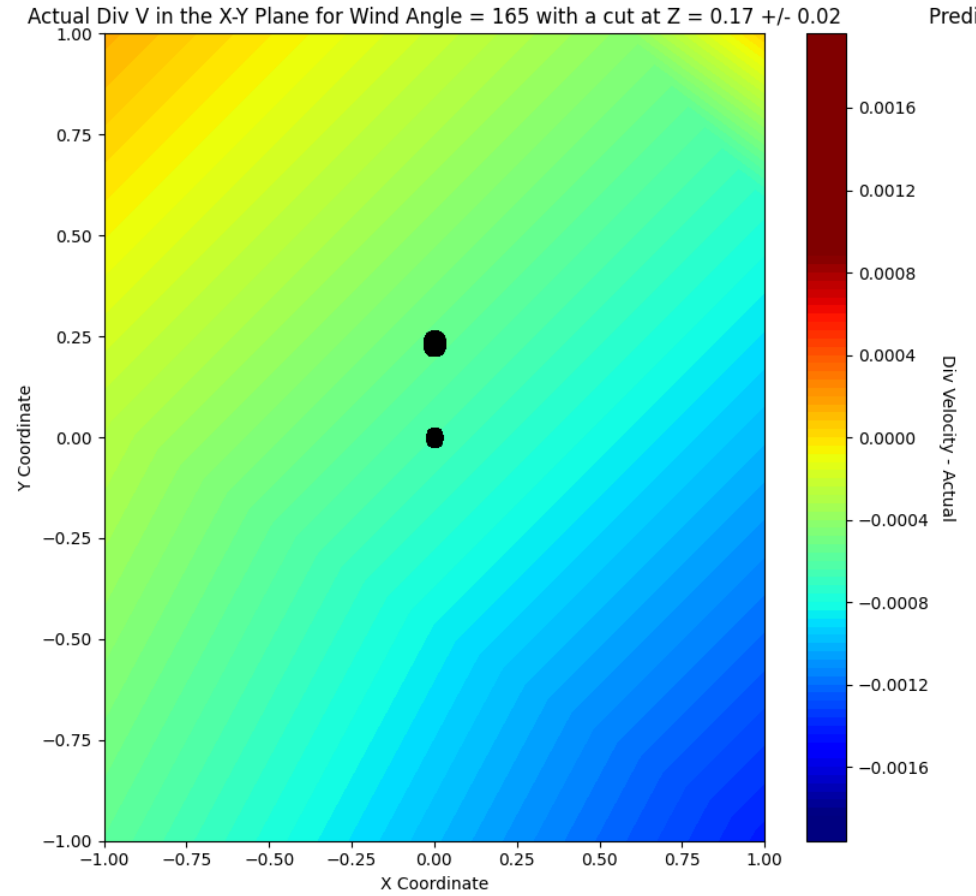


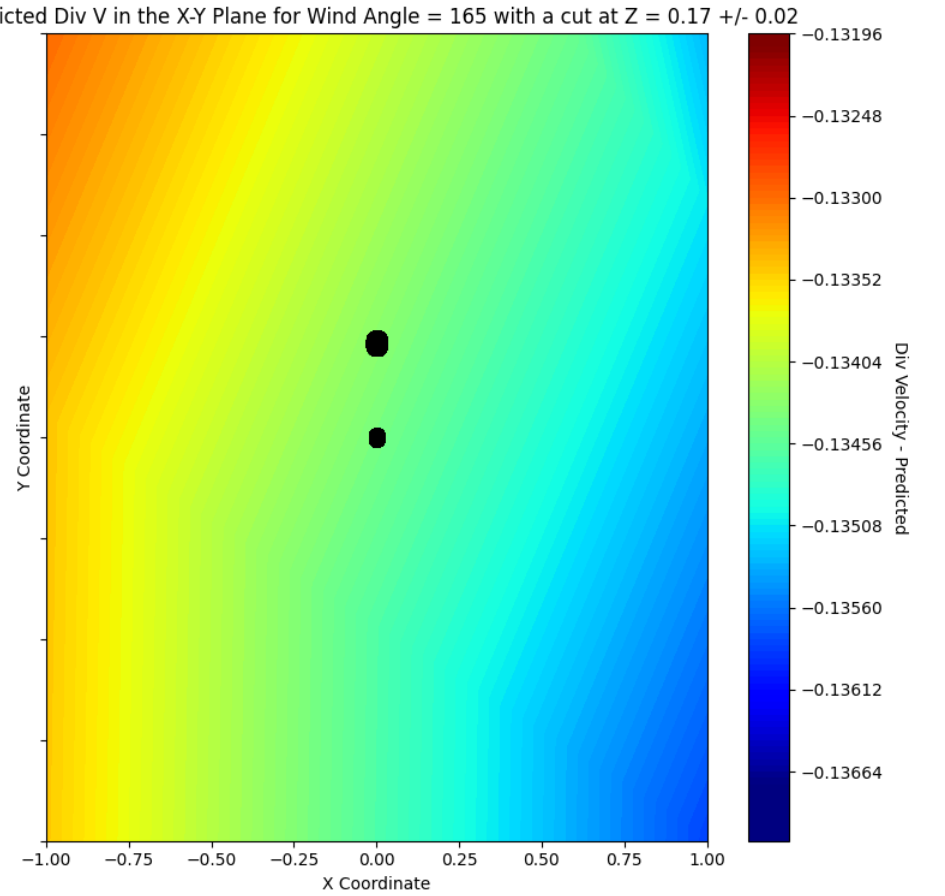


Comparison of Actual vs. Predicted values with Wind Angle = 150 in the X-Y Plane with a cut at Z = 0.17 +/- 0.02

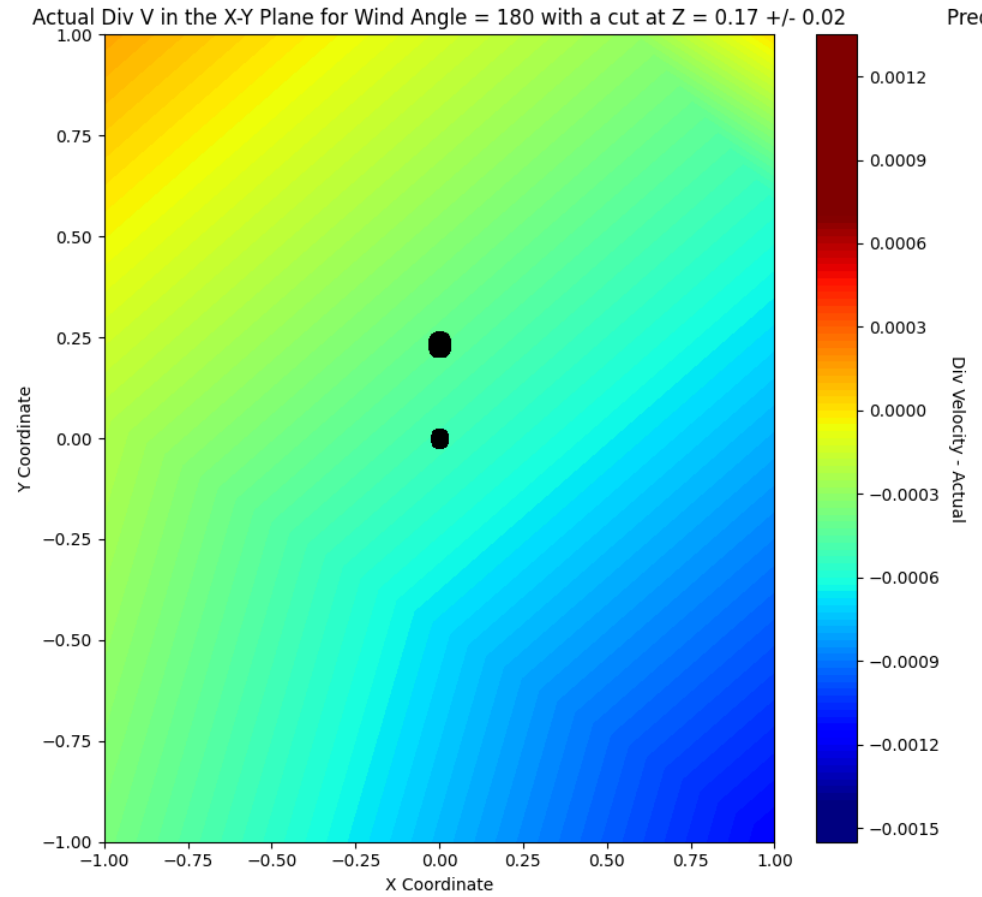


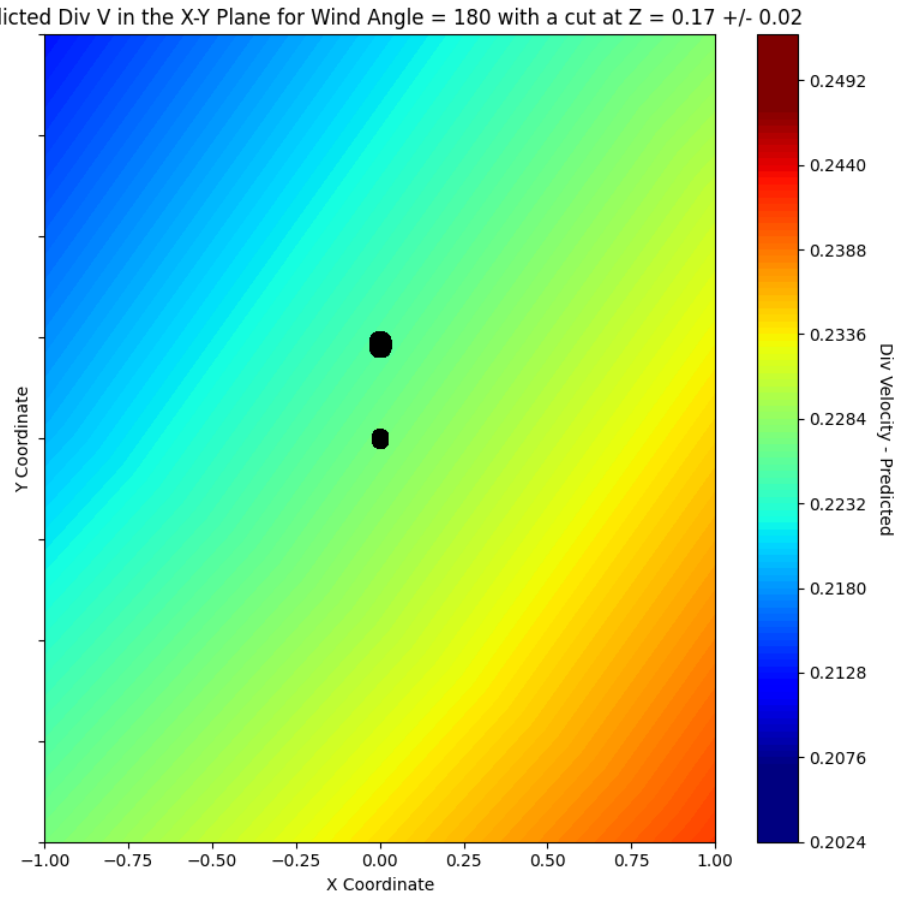
Comparison of Actual vs. Predicted values with Wind Angle = 165 in the X-Y Plane with a cut at Z = 0.17 +/- 0.02





Comparison of Actual vs. Predicted values with Wind Angle = 180 in the X-Y Plane with a cut at Z = 0.17 +/- 0.02





Some Next Steps

- La Defense